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Somewhere in a galaxy far away, other planets exist. That's probably of no surprise to readers of **All About Space**, but it's not until recently that we've managed to find evidence of alien worlds beyond the confines of our own Milky Way.

First astronomers found evidence for a planet orbiting a star in the nearby spiral galaxy Andromeda. With the help of microlensing, a phenomena that causes a star to act like a lens, the team concluded that a planet roughly six times the mass of Jupiter must be in orbit around it. Of course, the way in which the extragalactic world was discovered means that we're unable to complete any follow-up studies - microlensing is usually a one-off event, since it relies on the exact alignment between the 'foreground lens' and background object. Extragalactic planet searches are a tricky business, especially when it comes to confirming them.

A slightly different approach to uncovering these worlds came in 2018 when a team of researchers at the University of Oklahoma turned their attention to the quasar RX J1131-1231, some 6 billion light years away. They suspect that trillions of worlds populate it, with no other explanation for the lensing pattern they witnessed. This issue we head to the Whirlpool Galaxy, where a possible candidate was found this year.

I hope you enjoy the issue!

GEMMA LAVENDER

EDITOR-IN-CHIEF

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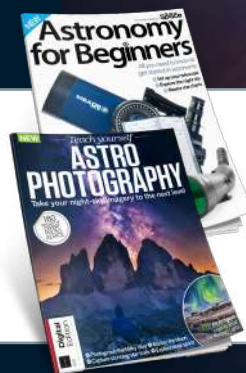
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The search for alien worlds continues, with exciting consequences.



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YOUR FIRST CONTACT WITH THE UNIVERSE





A galactic waterfall

NGC 2798 was discovered by William Herschel in 1788, while NGC 2799 was discovered in 1874 by Ralph Copeland. We can only imagine what those astronomers would have given to see this stunning image of the two barred spiral galaxies interacting.

As NASA has pointed out, the event appears to have formed a sideways spout, creating a galactic waterfall of stars as NGC 2799, to the left, is dragged into NGC 2798's centre. The interacting galaxy pair are in the constellation Lynx, and the image was captured by the Hubble Space Telescope.

Stellar skull

NGC 246 is a planetary nebula – an expanding shell of ionised gas that is ejected from red giant stars in the last throes of their lives. This one is in the southern constellation of Cetus about 1,670 light years away, and it's known as the Skull Nebula.

The European Southern Observatory's Very Large Telescope has captured it in all its pink and red glory using the FORS2 instrument. It consists of a couple of closely bound stars, which can be seen at the centre, and is orbited by a third outer star.



All hail the halo

A combination of natural and artificial light phenomena are behind this jaw-dropping image of a lunar halo – the Moon being the bright circle in the centre. The optical phenomenon was obtained in the sky above the European Southern Observatory's Very Large Telescope in Chile on a cloudy day at the Paranal Observatory.

Caused by the refraction of moonlight due to millions of small hexagonal ice crystals and water droplets suspended in the atmosphere around the Moon, it was viewable due to our planet's natural satellite being in perfect position relative to Earth.

And we have rollout...

The launch date may have been pushed back from late October following a glitch with a few Falcon 9 engines, but it didn't take long for preparations to get back on track. The mission? To send NASA astronauts Michael Hopkins, Victor Glover, Shannon Walker and JAXA astronaut Soichi Noguchi to the International Space Station for a six-month science mission, courtesy of SpaceX.



Bubbles in the early universe may have filtered heavy dark matter

Cosmic bubbles may have forged dark matter

Words by Tim Childers

Ballooning cosmic bubbles in our early universe may have led to the current abundance of dark matter. "Although we know how much dark matter our universe contains, for decades now we've been left wondering about dark matter's nature and origin," said Andrew Long, an assistant professor of physics at Rice University in Houston. "Is dark matter a collection of elementary particles? If so, what are the properties of these particles, such as their mass and spin? What forces do these particles exert and what interactions do they experience? When was the dark matter created, and what interactions played an important role in its formation?"

Long and physicists Michael Baker, at the University of Melbourne in Australia, and Joachim Kopp, at the Johannes Gutenberg University in Mainz, Germany, looked at the earliest period of the universe's formation, a fraction of a nanosecond after the Big Bang started. It was a battleground of particle creation and destruction, where particles collided and annihilated each other as quickly as they formed. The universe was a fiery soup of extremely high-energy elementary particles. This primordial soup was unimaginably hot and dense,

and far too chaotic for more ordered subatomic particles such as protons and neutrons to form.

This cosmic shootout did not last long. After the universe began to expand, the plasma gradually cooled, and the production of new particles came to a halt. At the same time, particles grew further apart, and the rate of collisions plummeted until their numbers remained fixed. The particles that were left are what scientists call 'thermal relics', and became the matter we know and love today, such as atoms, stars and, eventually, people. "In addition to all of the elementary particles known today, there's reason to imagine there were other particles present during the early universe, such as dark matter," Long said.

The team assumed that in the fractions of a second after the Big Bang, the plasma underwent a phase transition similar to what happens now when matter moves from one state to another, such

as when bubbles of water vapour form in a pot of boiling water, or steam cools down to form water droplets. In this scenario, bubbles of cooled plasma formed abruptly in the boiling soup of the early universe. These bubbles expanded and merged until the whole universe transitioned to a new phase. "As these droplets expanded throughout the universe, they acted like filters that sifted dark matter particles out of the plasma," Long said. "In this way, the amount of dark matter that we measure in the universe today is a direct result of this filtration in the first fractions of a second after the Big Bang."

The walls of these bubbles would become barriers. Only dark matter particles with large masses would have enough energy to pass through to the other side inside the expanding bubbles. This would filter out lower mass dark matter particles and could explain the abundance of dark matter observed today.

"BUBBLES OF COOLED PLASMA FORMED ABRUPTLY
IN THE BOILING SOUP OF THE EARLY UNIVERSE"

Radio bursts may spring from asteroids around magnetic stars

Words by Charles Q. Choi

Mysterious repeating bursts of radio waves that fire in random patterns might come from neutron stars blasting asteroids with magnetic winds that travel at nearly the speed of light. Fast radio bursts, or FRBs, are intense pulses of radio waves that can give off more energy in a few thousandths of a second than the Sun does in nearly a century. Scientists only discovered FRBs in 2007, and much remains unknown about their origins because of their brief existence.

The mystery of fast radio bursts deepened when scientists discovered the first repeating fast radio burst in 2016. When astronomers see repeating patterns in celestial events, they often think celestial mechanics might play a role: a planet completing an orbit around its star, or a fast-spinning neutron star, known as a pulsar, that blasts radio waves from its magnetic poles, flashing like a lighthouse as seen from the perspective of Earth.

Now researchers suggest that asteroids orbiting neutron stars might help explain at least some repeating fast radio bursts, even those with random timing. The key to this concept is that strong winds of particles often blow outwards not just from live stars like our Sun, but from dead ones as well, such as pulsars. Since pulsars are highly magnetic, their winds are too, and since pulsars spin rapidly, completing up to hundreds of revolutions per second, their winds can blast out at relativistic speeds - that is, at nearly the speed of light.

The scientists calculated that an object orbiting a pulsar - perhaps an asteroid - would carve a wake in the pulsar's wind. An electric current would circulate around this wake, and when the pulsar's wind crossed this wake, the resulting magnetic disturbances would generate a very narrow and extremely intense beam of radio waves.



Bizarre planet with supersonic winds and vapourised-rock atmosphere found

Words by Meghan Bartels

Scientists think they have identified a lava world so dramatic that it might boast a thin regional atmosphere of vaporised rock where it is closest to its star. That exoplanet is called K2-141b, and was originally discovered in 2017. The world is about half as big as Earth, but orbits so close to its star, which is one class smaller than our own, that it completes several loops each Earth day with the same surface permanently facing the star.

Scientists predict that those factors mean that two-thirds of the surface of K2-141b is permanently sunlit - so much so that not only is part of the world covered in a lava ocean, but some of that rock may even evaporate away into the atmosphere. "All rocky planets, including Earth, started off as molten

worlds, but then rapidly cooled and solidified," said Nicolas Cowan, a planetary scientist at McGill University in Canada. Lava planets give us a rare glimpse at this stage of planetary evolution."

The planet's density is about that of Earth's, so the crust can be modelled as pure silica as a reasonably simplified representation. At the edges of the atmosphere, where temperatures drop, the gaseous rock could cool enough to fall back to the surface as precipitation. If the atmosphere is dominated by silica or silicon monoxide, that precipitation would mostly fall into the magma ocean, but if the atmosphere is predominantly sodium, the planet would look even weirder, with solid sodium oozing back towards the oceans.



HOW IT WORKS

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Strange rings suggest planets are formed earlier than thought

Words by Charles Q. Choi

Words by Charles Q. Choi

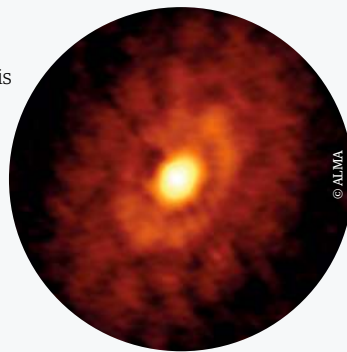
Rings detected around a newborn star may suggest that planets are born earlier than previously thought. Stars are born from dense clouds that collapse in on themselves under the force of their own gravity. As the blanket of gas and dust surrounding a nascent star, or protostar, shrinks over time, a disc forms around it that can give rise to baby planets, or protoplanets.

In a new study, Dominique Segura-Cox, an astronomer at the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, and her team investigated IRS 63, a protostar located about 470 light years away in the constellation of Ophiuchus. Previous research found this protostar is less than 500,000 years old.

IRS 63 is surrounded by a spinning disc of gas and dust that is relatively large for a young star, one more than 50 astronomical units (AU) wide, where one AU is the average distance between Earth and the Sun, which is about 93 million miles, or 150 million kilometres. "The size of the disc is very similar to our own Solar System," Segura-Cox said.

“Even the mass of the protostar is just a little less than our Sun’s.”

The scientists analysed IRS 63's disc using the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. They discovered it possessed two dark concentric rings, which appear to be gaps separating the disc into two bright concentric rings. If these gaps are caused by protoplanets carving their way through the gas and dust of IRS 63's disc as they circle the protostar, the researchers estimated the innermost gap was created by a nascent world nearly one-half Jupiter's mass, whereas the outermost gap was the result of a newborn planet nearly one-third Jupiter's mass. "We used to think that stars entered adulthood first and were the mothers of planets that came later, but now we see that protostars and planets grow and evolve together from early times, like siblings," Segura-Cox said.



Left
IRS 63
indicates stars
and planets
may grow
up together
more closely

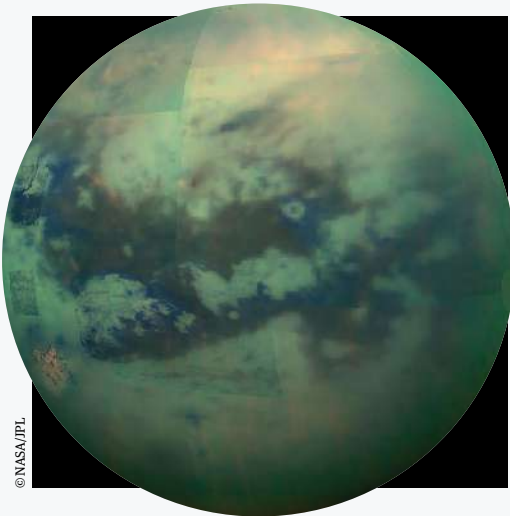
Weird organic chemical found on Titan

Words by Meghan Bartels

Saturn's moon Titan just keeps getting weirder - and more tantalising when it comes to scientists' hopes for life beyond Earth. Titan is perhaps the most Earth-like place in our Solar System, except the ingredients are jumbled up: ocean below ground, landforms of water ice instead of rock, rains of organic compounds and an atmosphere denser than our own. Now, two new research findings add still more intrigue to the strange moon, identifying an unexpected chemical in Titan's atmosphere and evidence of more complicated surface phenomena than scientists had previously realised.

Scientists' fascination with the chemistry of Titan is what makes the new findings so intriguing. Researchers turned the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile towards the moon and spotted the chemical signature of cyclopropenylidene, an awkward triangular compound made of three carbon atoms and two hydrogen atoms. Cyclopropenylidene is only the newest compound found. But finding it is surprising, the researchers say, because the little-known chemical is pretty friendly: if other compounds are near it, they tend to react, eliminating the cyclopropenylidene signature.

The newly spotted compound is also interesting because it is the second chemical found at Titan in which the carbon atoms lock in on each other to build a ring-like backbone. Other chemicals with that type of structure are crucial for the molecules that make up the information-containing part of DNA. "The cyclic nature of them opens up this extra branch of chemistry that allows you to build these biologically important molecules," said Alexander Thelen, a Goddard astrobiologist who worked on the research. The researchers later checked archived data gathered by NASA's Cassini mission, which studied the Saturn system from 2004 to 2017, and saw supporting evidence for cyclopropenylidene in those observations.



Left: The compound has interesting implications in the search for life

Right: The Falcon 9 launched and landed successfully



SpaceX launches next-gen GPS satellite for US Space Force

Words by Amy Thompson

SpaceX successfully launched an advanced GPS satellite for the US Space Force on 5 November, marking the first launch in nearly two weeks from Florida's Space Coast. One of the company's two-stage Falcon 9 rockets blasted off from Space Launch Complex 40 at Cape Canaveral Air Force Station, carrying the GPS III SV04 satellite to orbit. Nine minutes later the rocket's first stage touched down on the deck of *Of Course I Still Love You*, one of SpaceX's two drone ships.

The GPS III SV04 mission had been set to follow on the heels of a United Launch Alliance (ULA) Atlas V rocket, which was scheduled to loft a US spy satellite from Cape Canaveral on 3 November. The flight marks the third GPS delivery for SpaceX. Two previous advanced GPS III missions also launched on Falcon 9 rockets, including one this past June. Another of the satellites launched on the final flight of ULA's Delta IV Medium in August 2019.

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ALIEN WORLDS IN FARAWAY GALAXIES

EXTRAGALACTIC PLANETS

The search for alien worlds continues,
with surprising consequences

Reported by Colin Stuart



e should count ourselves lucky. For thousands of years humans have gazed up at the night sky, wondering whether or not we are alone. We are among the first generations to know for sure that our Solar System is just one of many strung out across the vast cosmos. Our discovery of around 4,000 alien worlds dancing around distant stars - known as exoplanets - over the last three decades has quite rightly been lauded. It's a wonderful achievement that helps put us in our astronomical place. The haul has thrown up a zoo of exciting and enchanting worlds, from those that dance around two suns to planets with diamond rain, bubbling metal lava and possibly even liquid water.

WHERE HAVE WE DISCOVERED EXTRAGALACTIC PLANETS?

Source: Wikipedia Commons © Adam Evans



ANDROMEDA

Potential planets: One

What do we know? It's six times the mass of Jupiter

Our nearest major galaxy, Andromeda sits 2.5 million light years from us. Its relative proximity means it represents one of our best shots at finding extragalactic exoplanets. It's home to at least double the number of stars found in the Milky Way.



© NASA

RXJ1131-1231

Potential planets: Trillions

What do we know? They range in mass, from the Moon up to Jupiter

This galaxy is lensing the light from a distant quasar sitting around 6 billion light years from Earth. It has a central supermassive black hole that tips the scales at 130 million solar masses.



© NASA, ESA & Hubble

M51

Potential planets: One

What do we know? Similar in size to Saturn and orbiting at least as far out as Uranus and Neptune

This galaxy is accompanied by a dwarf galaxy that has interacted with its host in the past. It sits ten-times further away than Andromeda and is less than half as wide as our Milky Way.

Despite the accolades, these discoveries are rarely put into their true context. It is easy to forget just how much of the universe's real estate remains unexplored. All of the confirmed planets found to date reside in our own Milky Way galaxy, and in our tiny corner of it to boot. There are around 2 trillion other galaxies in the observable universe. To see how much we've poked around in so far, imagine that this hoard of galaxies is represented by the total land area of the Earth. On that scale, our Milky Way accounts for the space taken up by the average UK bungalow. The area that includes the thousands of exoplanets we've found so far is smaller than a sock drawer in the spare bedroom.

Below: Some of the potential exoplanets could actually be miniscule black holes

It's no surprise that astronomers would love to know more about planets beyond our current horizons, and those outside the confines of our own galaxy in particular. "They are so unimaginably far away that we're unlikely to ever be able to reach them, but knowing about extragalactic planets is still really useful," says Lewis Dartnell,

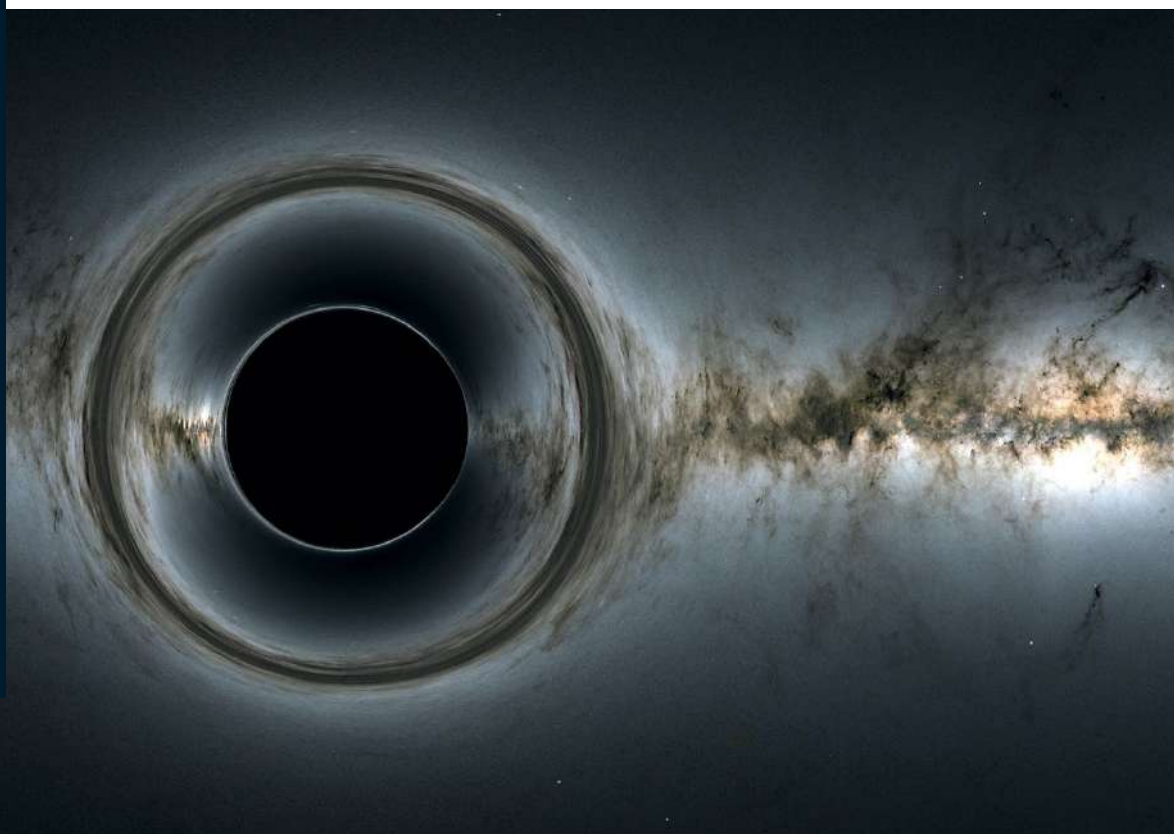
an astrobiologist at the University of Westminster. "They help build up the stats we have on the wonderful diversity of different worlds that exist."

There's every reason to suspect that they are out there. After all, a huge part of our understanding of space hinges on the fact that there's nothing special about the part of space we occupy. This so-called Copernican principle - named after the Polish mathematician and astronomer Nicolaus Copernicus - tells us that if there are planets here, there should be planets everywhere. However, as Dartnell says, the distances involved are intimidating. Spotting an Earth-sized planet in the Milky Way is hard enough - it's the same as trying to see an ant on the Moon. Seeing one in our nearest major galaxy, Andromeda, is a whole new ball game. It's the equivalent of being able to see a virus on the lunar surface. To photograph one we'd need a telescope a hundred-times wider than the entire Earth. With that clearly out of the question for the foreseeable future, the big question is whether there are other ways to find them.

Back in 2010 astronomers thought they had discovered an extragalactic exoplanet, albeit one that now resides in the Milky Way. The planet, HIP 13044 b, was found orbiting a star in a region of our galaxy called the Helmi stream. It's the remnant of a dwarf galaxy that was swallowed by our Milky Way between 6 and 9 billion years ago, meaning the planet likely formed outside of our galaxy before being consumed into it. However, follow-up work concluded that the planet probably doesn't exist and was a figment of incorrect data analysis.

A year before that discovery, another team of astronomers claimed to have teased out

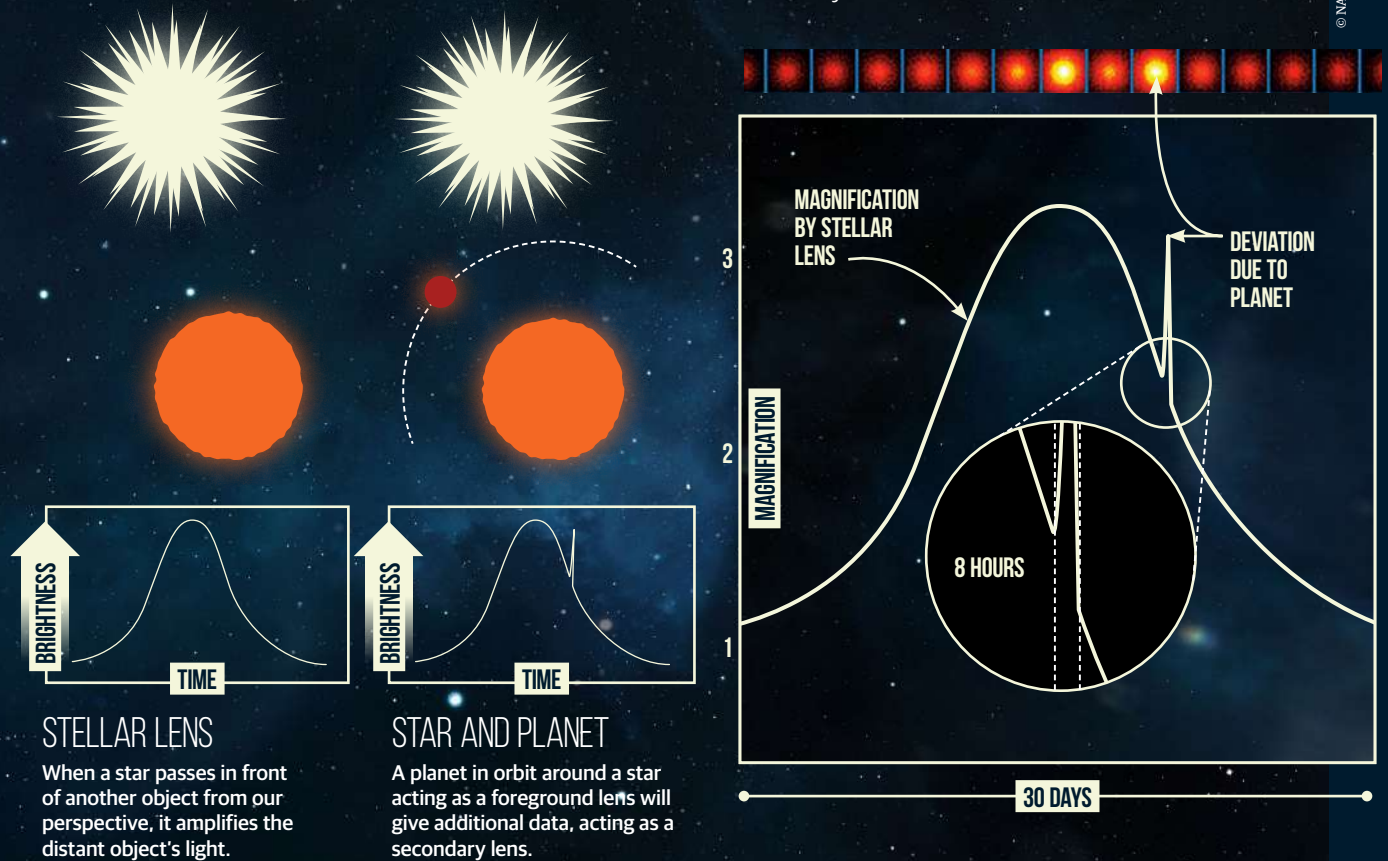
"THEY ARE SO UNIMAGINABLY FAR AWAY THAT WE'RE UNLIKELY TO EVER BE ABLE TO REACH THEM" LEWIS DARTNELL



© NASA

HOW MICROLENSING WORKS

How a galactic middleman allows us to see deeper into the universe more clearly



the presence of an extragalactic exoplanet in Andromeda. Their find relied on a technique called gravitational microlensing. Massive objects warp the space around them. Earth, for example, is caught in the distorted space created by the presence of the Sun, just as the Moon is caught in the distorted space created by the Earth. This warping of space can act like a lens, magnifying light from a background object as it makes its way around a massive object like a star or galaxy on the long trek to Earth. You can see a similar effect if you look at an object through the curved base of a wine glass. Astronomers can glean some details of the object acting as a lens from the exact way the background light gets magnified.

When astronomers looked at a star acting as a lens in Andromeda, there appeared to be more lensing than the star alone could provide. They concluded that the star was accompanied by a planet six times the mass of Jupiter, and this was adding a little extra lensing. However, that's all we can say about it. "The way that these planets are

discovered means we're unable to do any follow-on studies," Dartnell says. Each lensing event is a one-off, as it relies on an exact alignment between a foreground lens and background object. This geometry is unlikely to be repeated again, and so we are unable to probe the system further or check to see if the planet is really there at all.

In 2018 there came a slightly different approach. A team of astronomers led by Xinyu Dai from the University of Oklahoma may have found trillions of extragalactic exoplanets in one fell swoop. This time they were looking at an entire galaxy some 3.8 billion light years away that was lensing light from an even more distant quasar. The pattern of lensing they observed could not be explained using the galaxy's stars alone. They modelled different ways to explain the discrepancy, settling on the presence of a huge number of unseen objects ranging in mass from the Moon all the way up to Jupiter.

"They could be free-floating planets," Dai says. Also known as 'rogue' planets, they are worlds jettisoned from young solar systems as newly

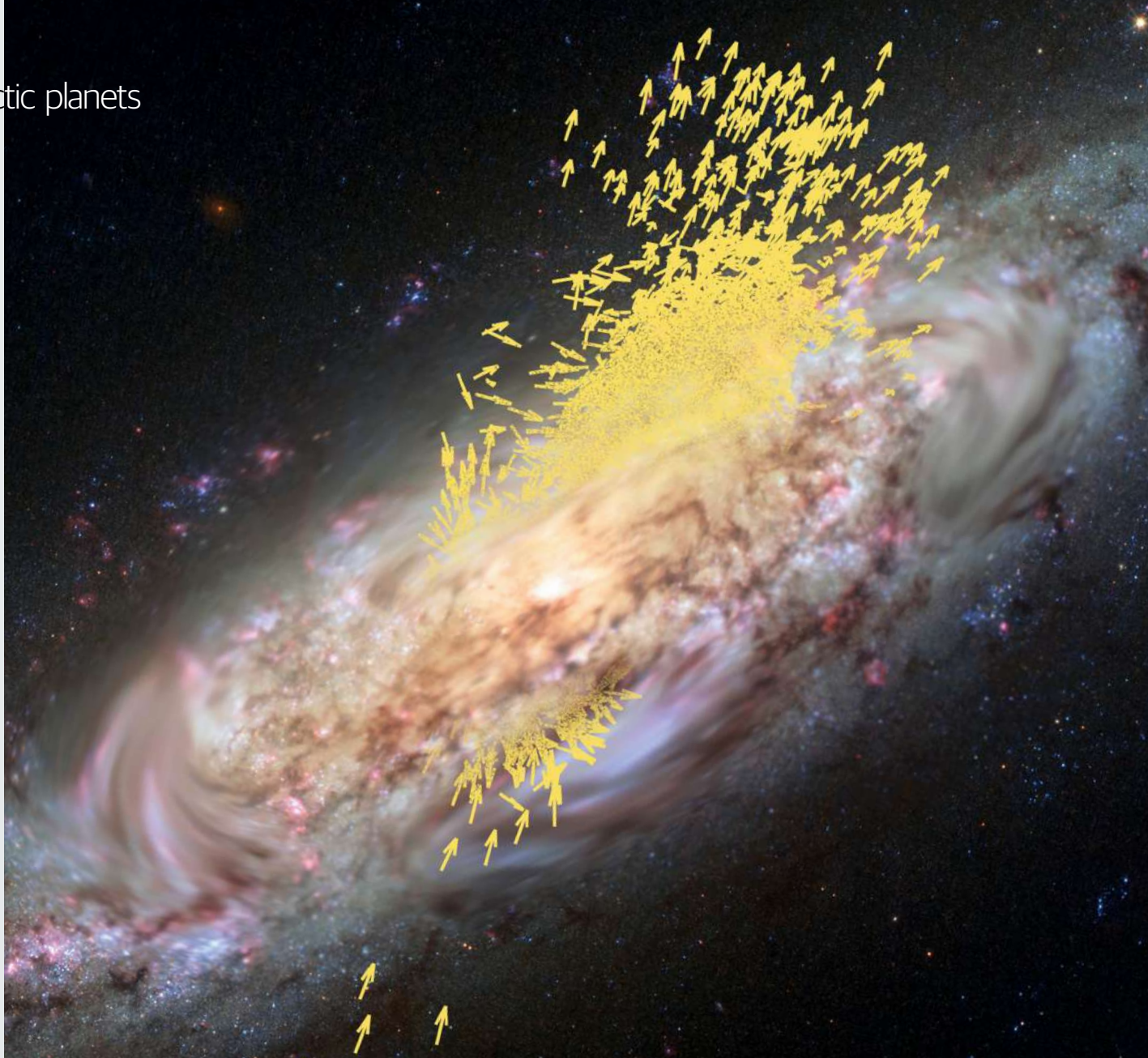
Right:
Copernicus told us that there's nothing special about our place in the universe



Source: Wikipedia Commons/PUBLIC Domain

Right: An extragalactic exoplanet could have been absorbed into the Milky Way

© ESA



“THEY HELP BUILD
UP STATS ON
THE WONDERFUL
DIVERSITY OF
DIFFERENT
WORLDS”

LEWIS DARTNELL

formed planets jockeyed and jostled for superiority. We’ve already found rogue planets wandering between the stars in our own Milky Way galaxy, so it’s no surprise to find them elsewhere in the universe. According to Dai’s calculations, there could be 2,000 rogue extragalactic exoplanets for each and every one of the billions of ordinary stars in this distant galaxy.

While planets may be the most obvious contender, it’s not the only option they are considering. “All we can tell is the mass of these objects,” says Dai’s student Saloni Bhatiani. “We can’t yet say anything about their size,” she says. So there is a chance that they aren’t planets at all, but primordial black holes instead. Black holes are normally associated with the deaths of massive stars, but many cosmologists believe that miniature versions were created not long after the Big Bang. A black hole that weighs the same as Earth would measure just one centimetre (0.3 inches) across.

Until we can work out the physical size of these objects it is hard to tell the difference between

primordial black holes and rogue extragalactic exoplanets and whether the missing mass can be explained by a combination of the two. Thankfully that’s not beyond the realms of possibility.

“With better data we think we can constrain the properties of individual objects,” says Dai. They’ve already seen a similar effect in two other galaxies and have three more lensing galaxies in the bank awaiting further analysis. In the meantime, we’re still waiting for the first cast-iron proof of an extragalactic exoplanet.

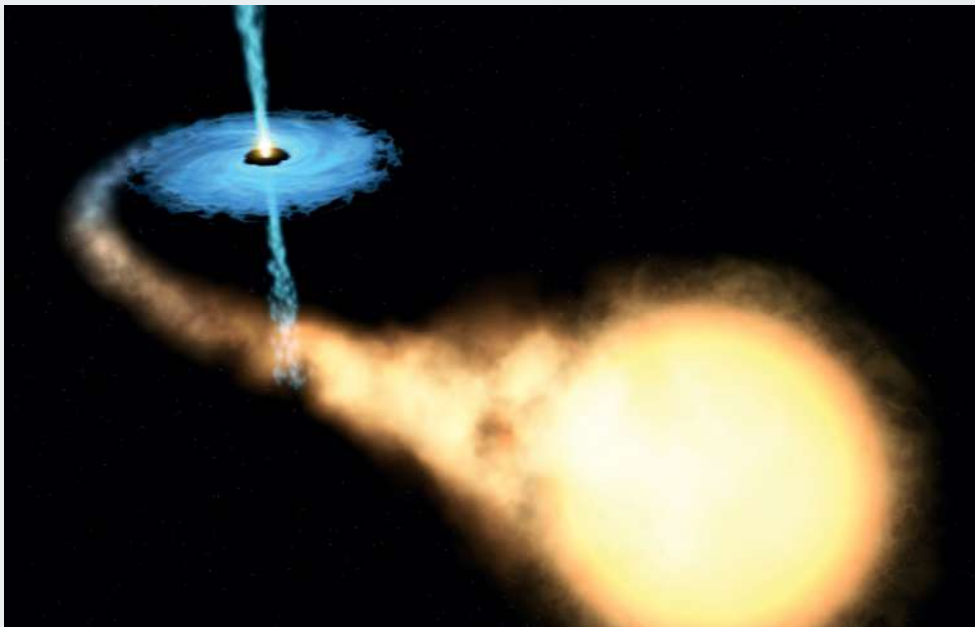
Another team of astronomers threw a possible candidate into the ring in September 2020. Led by Rosanne Di Stefano at the Harvard-Smithsonian Center for Astrophysics, they think they’ve spotted an exoplanet in the Whirlpool Galaxy, Messier 51 (M51). At 30 million light years away, the galaxy is quite close to us in cosmic terms – you can see it through a telescope in the constellation of Canes Venatici, not far from the famous seven saucer-shaped stars of the Big Dipper. The potential new planet, with the trip-off-the-tongue name of

© NASA



Left: NASA's Chandra X-ray telescope, which was used to spot an exoplanet in M51

Below: The potential planet found in M51 orbits an X-ray binary similar to this one



© NASA/ESA

EXTRAGALACTIC PLANETS BY THE NUMBERS

2010

Year of the first possible extragalactic planet discovery

2 TRILLION

The number of other galaxies in which to look for planets

4,374

The number of exoplanets found in our own Milky Way

1999

The year NASA's Chandra X-ray Observatory launched

0.12

The size in millimetres of the smallest potential primordial black hole in RXJ1131-1231

M51-ULS-1b, is not your common or garden world, however. For starters it is in a binary system - it orbits two objects instead of one. One of those objects is a compact dead star - either a neutron star or black hole - and the other is a huge star.

The two objects are a brilliant source of X-rays, producing at least 100,000-times more X-ray energy than the Sun emits across all forms of light. Using the Chandra X-ray Observatory, Di Stefano saw the star dim for a few hours, hinting that a planet may have got in the way and temporarily blocked out our view of the X-ray light. This technique - called the transit method - is one way that we find conventional exoplanets. However, one transit isn't usually enough to be confident you've found a new world. If it really is an orbiting planet, you would expect to see subsequent transits as the planet comes round in front of the stars again. Normally it takes three transits to be confident that the variation in light you're seeing isn't being caused by something else. Perhaps the X-rays are dimming for another entirely unrelated reason.

If it does turn out to be a planet, Di Stefano's calculations suggest it would be a gas giant a little smaller than Saturn. One that orbits the binary stars at a distance tens of times further than Earth's distance from the Sun. Those characteristics alone would make it an extremely unlikely place to find liquid water and life. But the huge amount of X-ray radiation present in the system draws a line through the prospect entirely.

So far these potential extragalactic exoplanets have been discovered using some of the same techniques we use to find exoplanets in our own galaxy. However, Camilla Danielski and Nicola Tamanini believe that an exciting new technique is already in the pipeline - one that relies on gravitational waves.

First discovered in 2015, gravitational waves are ripples in the very fabric of space itself, generated by events occurring within it. The collision of two black holes, for example, sends gravitational waves soaring outwards at the speed of light. Just such an event provided the first-ever gravitational waves to

be detected. They've become so commonplace now that the Laser Interferometer Gravitational-Wave Observatory (LIGO) picked up more than one event a week in 2019.

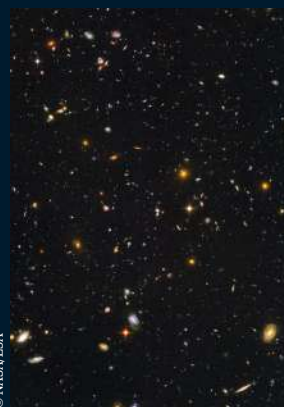
This elaborate machine works by sending laser beams down two four-kilometre (2.4-mile) arms at right angles to each other. The lasers hit mirrors at the ends of the tunnels and are reflected back to the start. As the two arms are the same length, usually the two laser beams arrive back at the same time. However, if a gravitational wave passes through, it changes the length of one of the arms and one laser arrives ahead of the other. While this may sound simple in principle, it's exceptionally subtle in practice. One arm changes in length by the width of a proton - the positively charged particle in the heart of an atomic nucleus. It's the equivalent of the 40 trillion kilometre (24 trillion mile) distance to the nearest star after the Sun changing by the width of a human hair.

Such a machine is good for picking up cataclysmic events like the collision of mighty black

WHY DO WE THINK THERE ARE PLANETS IN OTHER GALAXIES?

We used to think that we were at the centre of everything. That the Sun, planets and stars all rotated around the Earth. The Copernican revolution changed all that, relegating us to just another planet orbiting the Sun. We realised that the stars were just distant copies of the Sun. Much of modern astronomy hinges on the idea that there's nothing special about our place in the universe. This is called the Copernican principle. This means that if there are planets here there should be planets in other galaxies too.

We also know that planets are a natural by-product of star formation - they form from the leftovers. Wherever we see stars, we also expect to see planets too. The growing field of astrochemistry has also provided evidence that other galaxies contain complex molecules required to fashion the building blocks of life. It is increasingly unlikely, it seems, that we are the only living planet in the entirety of the universe. Yet finding undeniable evidence that's really the case is a significant challenge that the next generations of astronomers will try hard to meet. Whether we are alone is perhaps the biggest question scientists can ask.



© NASA/ESA



Above: When the Sun dies it will form a planetary nebula, becoming the central white dwarf

Below: This upcoming mission could be used to spot planets using gravitational waves

holes, but according to Danielski and Tamanini, we need an even bigger gravitational-wave detector if we're going to use them to discover extragalactic exoplanets. "They emit gravitational waves in a different frequency range to LIGO," says Tamanini, a researcher at the Max Planck Institute for Gravitational Physics in Germany. To pick them up we need a detector with arms significantly longer than LIGO's. Fortunately such a machine is already being planned: the Laser Interferometer Space Antenna (LISA).

With a prospective launch date planned for 2034, LISA is a European Space Agency (ESA) mission consisting of three spacecraft flying in formation to create an equilateral triangle in space. Each side of the triangle will be 2.5 million kilometres (1.5 million miles) long. Back in 2015 the ESA successfully flew the LISA Pathfinder mission to test out the feasibility of building the full mission.

Danielski and Tamanini think LISA will be perfect for detecting planets orbiting around binary white dwarf stars. A white dwarf is the Earth-sized core of a Sun-like star after it has shed its outer layers at the end of its lifetime. Two white dwarfs orbiting each other create gravitational waves in

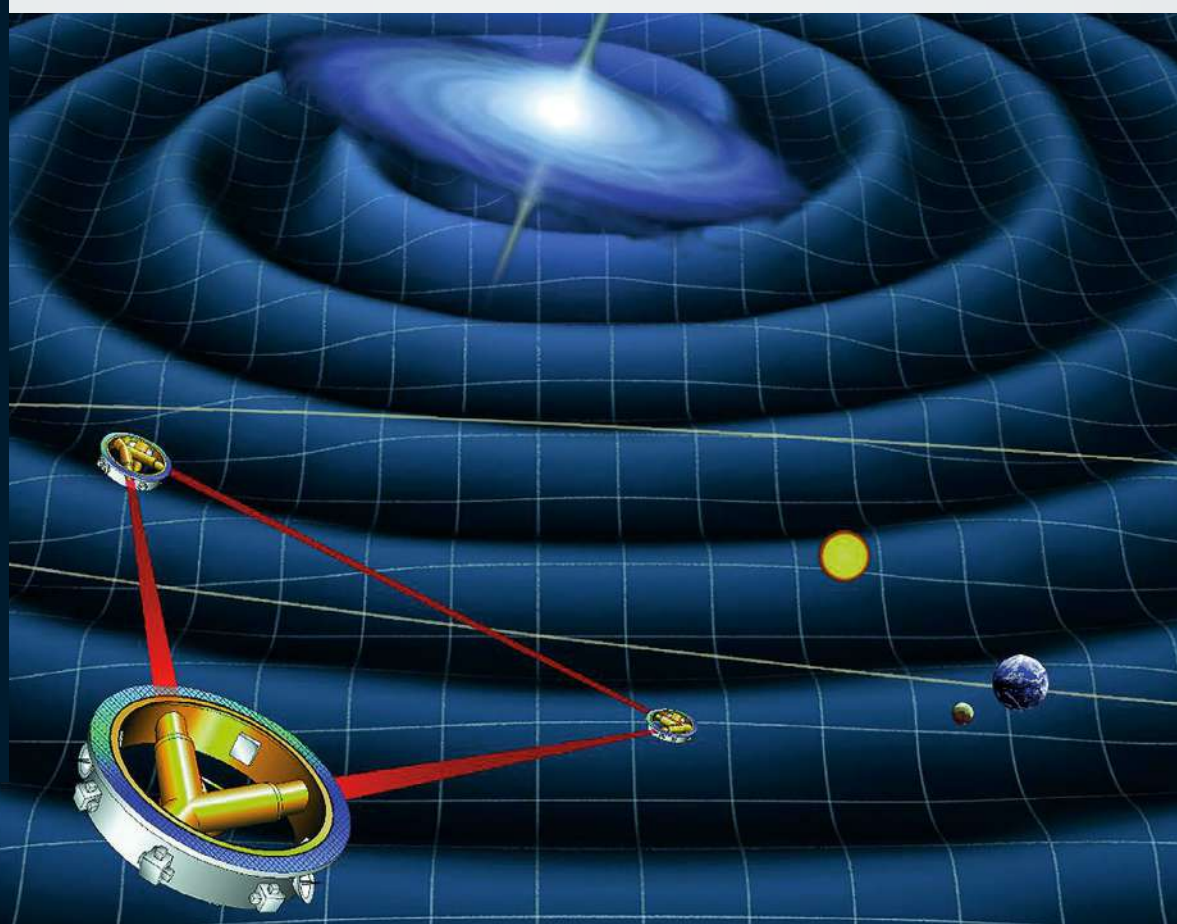
just the same way as two conjoined black holes do. However, the presence of a planet in orbit would change things. "Its gravitational pull upsets the regularity of the waves," says Tamanini. According to their calculations, LISA will be able to pick up planets orbiting binary white dwarfs in the Magellanic Clouds - the two dwarf galaxies that orbit our Milky Way.

Not only will this tell us more about the nature of extragalactic exoplanets, it could also be a crystal ball into our own future. We know very little about what happens to planets when their stars die. "It is going to allow us to pin down the life of a planet in a phase we don't know about," says Danielski, who works at the Centre for Space Exochemistry at University College London. "We are seeing the future of our Solar System," she says. Although the Sun doesn't have a binary companion, it will turn into a white dwarf in around 7 billion years. Discovering these planets could help us understand what will happen to Earth when it does.

After all, that is what hunting down exoplanets is all about. They allow us to hold up a mirror to ourselves, giving us a clearer picture of who we are and how we fit into the rich and vibrant tapestry of the universe.



Colin Stuart
Astronomer & space science writer
Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour: 15347 Colinstuart.



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MARTIAN MOONS EXPLORATION

Japan's next sample-collection feat will be to the second and third closest natural satellites in the Solar System

Japan has a very adept space agency in terms of exploration. The Japan Aerospace Exploration Agency, or JAXA, has engineered the launches of the Hayabusa missions to near-Earth asteroids and the Akatsuki space probe to Venus. Although the Hayabusa2 spacecraft is the only mission so far to occur without a hiccup, there is much to learn from these mistakes, and JAXA is now readying itself to launch a new mission to Mars' moons, Phobos and Deimos.

JAXA is currently preparing its Martian Moons Exploration (MMX) mission, with a plan

to launch towards Phobos and Deimos in 2024, gain scientific data from both objects upon arrival in 2025, collect a sample of Phobos in the process and finish the mission by returning the sample to Earth by 2029. Russia's space agency, Roscosmos, attempted the same feat in 2011 with the Fobos-Grunt mission. However, untimely rocket burns meant it did not reach a trajectory toward Mars, but instead became stranded in low-Earth orbit, ending with a controlled re-entry into the Pacific Ocean.

The main aim of the MMX mission is to investigate the origins of these two moons.

Astronomers have never been able to truly understand the origins of Phobos and Deimos, which are 23 and 12 kilometres (14 and 7.5 miles) in diameter respectively. There are two leading theories as to how they formed. The first is that they are captured asteroids from the nearby asteroid belt. If this turns out to be correct, this could mean they may have transported water, volatiles or other organic compounds from further regions of the Solar System.

The second explanation is that they were formed after a huge collision involving the Red Planet, implying that these moons are essentially

1 Three sections

MMX can be split into three sections: the propulsion module, the exploration module and the return module.

3

3 Choosing Phobos over Deimos

Phobos was deemed more scientifically desirable for collection of a sample because of its closer proximity to the Martian surface - plus it has more data already available.

5

2 International collaboration

The MEGANE and MacrOmega instruments are being developed with NASA and France's National Centre for Space Studies (CNES) respectively.

frozen time capsules leftover from the planet's formation currently suspended in orbit, and could reveal a lot about the planet's past.

The new spacecraft will be well equipped with an instrumental suite capable of providing an extensive remote investigation of the moons' surfaces. This high-tech instrumental suite will consist of a gamma-ray and neutron spectrometer (MEGANE), a wide-angle multiband camera, a near-infrared spectrometer (MacrOmega) and several other cameras, sensors and spectrometers. But the centrepiece of the spacecraft will be its sample-collection suite.

JAXA is aiming to take what it has learnt from Hayabusa2 - which is currently on its way back to Earth carrying a sample of the asteroid Ryugu - and enhance it. Hayabusa2 was designed to collect a small sample of just 0.1 grams (0.004 ounces), but the MMX team

need the spacecraft to gather a minimum sample of ten grams (0.4 ounces). The MMX sample-collection suite literally needs to be a hundred times better. There is no doubt that this call for technological improvement will be answered as this exploration mission develops.

On 19 February 2020 the MMX team announced that the mission has shifted from the pre-project phase into the development phase. This exciting news means that the team can begin working on the spacecraft's hardware and software and preparing the craft for launch. "In order to transition from a JAXA pre-project to project," stated the team on the official mission website, "the MMX mission team had to consider factors such as the importance of the scientific goals, the success criteria, the implementation system, the financial plan, schedule and identify risks and countermeasures."

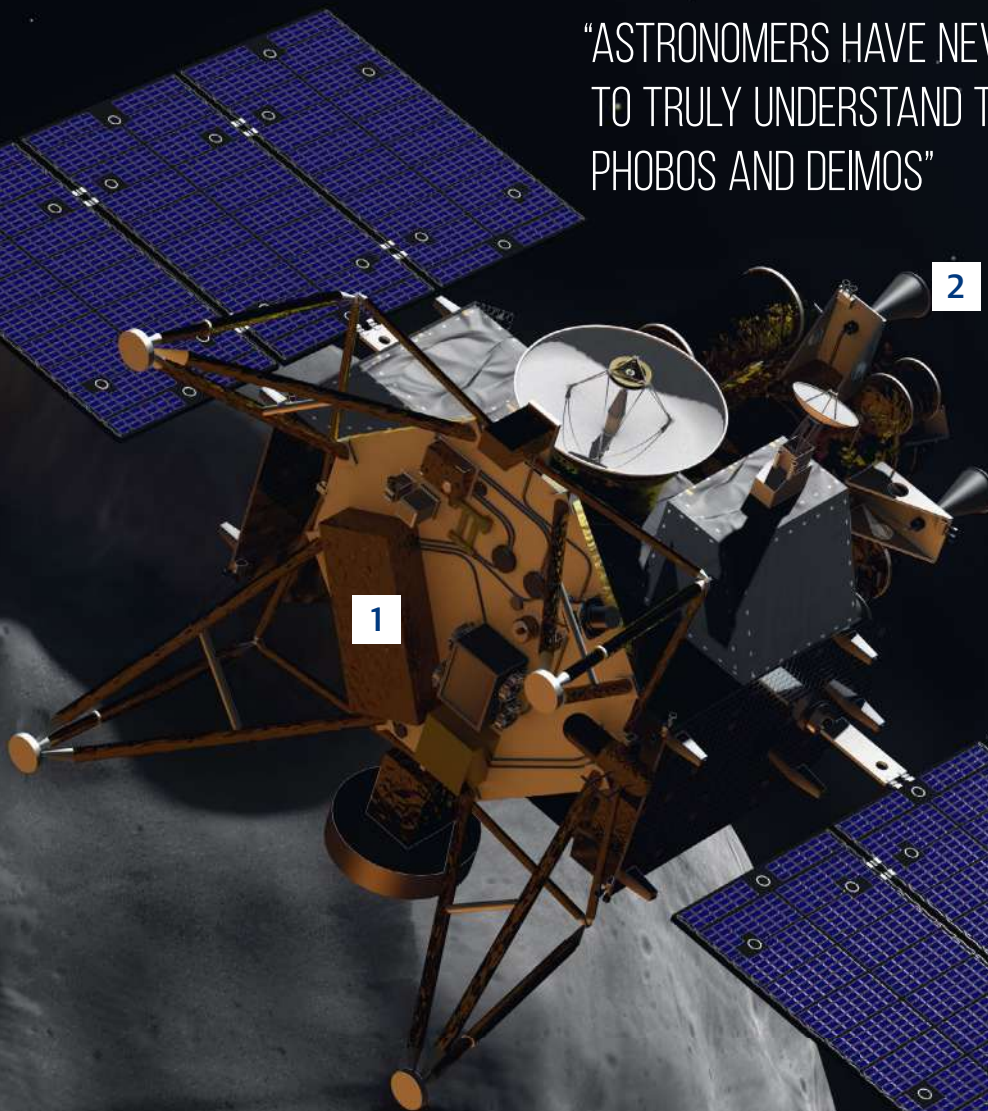


4

4 Asteroids or ancient Martian rock?

Astronomers want to determine if these moons are asteroids caught by Martian gravity and pulled into orbit or ancient ejecta and debris leftover from a huge collision which has coalesced to form an orbiting body. The results for each of the moons could be different.

"ASTRONOMERS HAVE NEVER BEEN ABLE TO TRULY UNDERSTAND THE ORIGINS OF PHOBOS AND DEIMOS"



1

2

5 A long time coming

JAXA first began pondering the feasibility of a sample-return mission to Phobos in 2015.

INTERVIEW

“

BIO

Dara Ó Briain
Ó Briain is an Irish comedian, science communicator, TV host and author. He studied mathematics and theoretical physics at University College Dublin (UCD), Ireland, before pursuing a career in comedy. His career has seen him co-host the BBC's *Stargazing Live* with Brian Cox, and he has written a trifecta of space books aimed at young adults, the most recent one being *Is There Anybody Out There?*





IS THERE ANYBODY OUT THERE?

All About Space speaks to *Stargazing Live* co-host and astronomy-mad comedian Dara Ó Briain, who divulges how isolation has revealed the wonders of astrophotography, his memories of the BBC hit show and whether life could be out there somewhere in the cosmos

Interviewed by Lee Cavendish

During the several months of lockdown and social restrictions throughout 2020, have you been able to get stuck into any observing?

Yeah hugely, because now, from what I've gathered from talking to the many specialist telescope shops, I've been slowly building up my store of small black metal tubes.

It became a very huge thing, because the lockdown had seven weeks of clear skies, so I very quickly took to it. I had a couple of ones [telescopes] that were very small, you know, ones that I've had for years, and I thought, let's just get a proper eight-inch CT [Cassegrain telescope] and see what we can see. It was because Venus was up, I think, initially, and then there was the Saturn-Jupiter thing that was a big thing for a while. But I've gone down the rabbit hole of doing deep-space stuff now, and that's a whole other world of pain. But it's been great. It's been lovely - to the point where I'm packing up this stuff at three in the morning - and one night, I went: "Oh my God, I've got a hobby. I haven't had a hobby in years."

The high point of the whole thing was NEOWISE. There was one night where the clouds opened and I could actually get a shot of it. I had, at that stage, still enough to get both the skyscape normally and also then notch up the telescope and get it close up, so it was green with the tail behind it. I've got a lot to learn, but I got it green, so I'm very happy. I

totally get the thing where they say to get your kids into astrophotography, because they'll never have the money to spend on drugs.

You were part of the BBC's *Stargazing Live*. Do you have any favourite memories from creating the shows?

There was a point where not only did we have the basic show - the one-hour-long show that was itemised - it was followed by a 30-minute, much more relaxed conversation programme called *Stargazing Live: Back to Earth*. Often, in its ideal form, we never had time to rehearse it, because the other show was really polished. We're running from location to location, now here's an interview that we have somebody here to tell us what they discovered and why it's important, and then we move onto the next thing. It was all really polished and lovely.

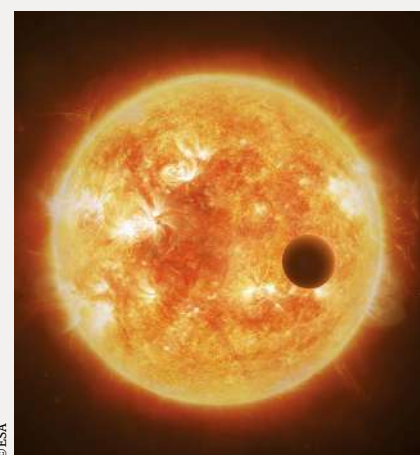
Then we had this half-hour show afterwards which was a much looser conversation, and there was a producer who would make it every year and would come in with their different ideas, and we would just then fling them out because we'd be having a conversation with that person who only gave three right answers in the original show, so we'd have them back on again.

At one stage, someone had some quiz where they got canines to ask a question or something, which is fine, but we had Buzz Aldrin and Chris Hadfield

in the studio. So there is someone in my ear going: "Two minutes to go to the canine. Okay, one minute until the canine question." And I'm thinking, no, I'm not going to do that! I can't tell you because I'm live on television, but screw that, it's Buzz Aldrin for God's sake.

We asked him about how he had to sleep on the Moon, and he was saying: "Oh yes, we couldn't sleep because we were so excited." And I was like, we're not leaving this conversation to go: "Where is this VT of the canine."

Right: Ó Briain makes a humorous comparison between the exoplanet transit detection method and a bee buzzing around a lamp



© ESA

Above: O'Briain emphasises that exoplanets are an exciting topic of discussion in his latest book

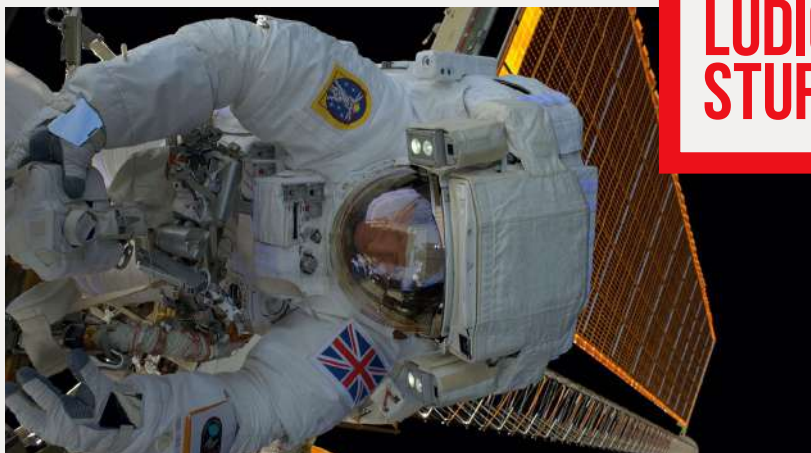
Right: *Stargazing Live's* coverage of Tim Peake's 2016 spacewalk was nominated for a BAFTA

Below: Jodrell Bank Observatory in Manchester, UK, is the usual venue for the filming of *Stargazing Live* episodes

4/4

NOBODY REALISES THAT ALL THIS LUDICROUS TECHNICAL STUFF WAS HAPPENING

7/7



© NASA/ESA



© Mike Peel, Jodrell Bank Centre for Astrophysics, University of Manchester

Any moments that made you nervous?

There was when we did the live coverage of the [partial solar] eclipse - which was at around 11 o'clock in the morning - and we were up in Jodrell Bank [Manchester, UK]. Standing around with us was the head of the BBC and all the other senior people, as it was a big event and we were covering it for the nation.

So the totality was happening above, I think, the Faroe Islands, but to capture it there was an aeroplane that was transmitting pictures to a relay station on the Faroe Island, so it had to stay within roughly a 50-mile [80-kilometre] radius. The aeroplane had to - if you can imagine the arc - conduct a turn about 51 miles [82 kilometres] away, while keeping the eclipse on the same side of the aeroplane so we got a continuous picture.

They had to pick an arc long enough to do the entire totality coverage, including the corona, the wedding ring and all that stuff. All that had to happen on one part of the plane. Nobody realises

that all this ludicrous technical stuff was happening. While this was happening, Brian and I were hanging out with school kids and trying to be casual about all this. The plane did its turn at the 51-mile [82-kilometre] mark, or whatever mark it was outside the range, so it could do the longest loop it could do, and it disappeared. It was outside of the range, so we got no pictures. Then we got a voicemail that we'd lost the pictures.

With 17 minutes left of television to fill, which was supposed to be peaking in about eight minutes with the actual eclipse, it's just me and Brian talking for 17 minutes while the head of the BBC was smiling and nodding along. We thought, 'oh my God, we're going to have to sell this entire thing. It could have happened. But then, when we were talking about a plan B and how we're going to talk our way through this, the picture returned and it was incredible. Incredible footage which showed everything that we needed to see, but that could have gone any number of ways.

We heard that there were some technical mishaps while filming...

There was the first one that managed to solve the technical problem of having somebody stand in front of the northern lights and get them and the northern lights in the same shot behind them, moving live. When you go to see the northern lights, you go, "yeah... I can sort of see them". But when you put the camera on it for a 15-second exposure with 1,000 ISO, then you go, "there are the northern lights! Doesn't it look amazing!" So a lot of it works on the camera. There was a lot of that technical stuff happening.

If I was ever on a show that deserved an award, a BAFTA or something like that, [it would be *Stargazing Live*] because there were some of those series of *Stargazing Live* that were real achievements. I used to get really angry, more in a joking way with a floor manager friend of mine, because she worked on the whale-watching live show [*Big Blue Live*], which beat us to the BAFTA

for the best live television [in 2016], and we had Tim Peake on the International Space Station! So when they did this whale-watching live programme, it was in the middle of one of their links where suddenly behind them there was a big spray and you go: "There's a whale right there!" And I was going, "you win this one".

You've recently written a book! Could you tell us a bit about it?

In any of these things, there's a whole universe of directions that you could go in to tell stories about space. And it's a case of how do we tell this amazing stuff again, but in a different way? So we've now done three of them, and this is the third one, and there's a general journey out into space in the first book, which was like how far can we travel, how far can we send robots, how far we can see. This was our structure for the first one, and that allowed us to expand out.

This one we decided to focus it around alien life, and that allows us to talk about how planets are formed. We find out how life can be on Earth, also what we hear from space and what we are sending out to space, in terms of [NASA's] Golden Record. All of that kind of stuff we cover, as well as exoplanets. There is a big section on exoplanets because we really wanted to do it. It's all about how it took us whatever number of years to discover three planets hundreds of years ago, and then in the last five years we've discovered another 5,000.

Something you do really well is explaining astronomical concepts while bringing a bit of a comedy factor to it. Is this difficult, and do you spend a long time trying to write these jokes and anecdotes?

You do it in a few passes. You go, 'what am I actually going to write about?' Then at all times, as it's a thing you do anyway from doing comedy shows, if you're looking for what's the silly thing in here and what's the ridiculous version, sometimes you get stuck explaining the actual science of it, and you think, 'oh, hang on. I haven't had a gag for a while.' It becomes a slightly more contrived sense of, for the rhythm of the book, I better go back and read this again and there should be a joke roundabout here. You do this on stage all the time anyway. If you're telling a story, you clock that you haven't had a laugh in a while, so I better make sure that there's a laugh here, just to keep them rolling along with it.

I think the ideas are interesting in themselves. It's not like I'm trying to create a spoonful of sugar, but it just changes the rhythm of it a bit. It adds to the flow of it a bit and also it makes it a bit silly. There's a whole thing about how you track exoplanets, and there is a long discussion of training a bee to fly in circles around a lamp. When you're looking at the lamp and then the bee goes past, and the light dips a bit because the bee went past, then we

forget about the bee and then it's, "look! The bee's back!" I'm essentially taking the transit method and finding a silly way of doing it. It's not like we're trivialising a thing - it's all fun and joy anyway, what we're talking about, but it adds to the flow in a fun way. That's why you come to me.

With a fleet of spacecraft currently heading towards Mars, they're all prepped and ready to search for life. With the recent news about Venus, do you think that we'll find signs of life on another planet soon?

Yes. I absolutely think we will because it's the next question, really. Particularly if we can do it on Venus as well, as it is relatively nearby. However, the missions that might go to Enceladus and Titan, I think are better candidates for finding life.

It is interesting, though, what the reaction would be to microbes being one of them because we've always suspected that to be the case. And certainly the odds are always going to be, at any given place it's likely going to be microbes. For us, I think Earth's microbes became multicellular after 2 billion years. But whether the public gets excited about microbes is a different thing.

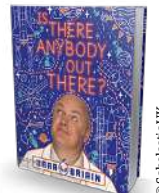
However, there are old panspermia issues about whether this means life didn't start here and all kinds of stuff that still have to be answered. I mean, let's drill down to the ice on Mars and let's have a look and see what we can find. It would be interesting if we found out that it's a much dirtier Solar System than we expected - for example if we find microbes in five different spots. Within the book, I don't make any promises that we're going to get a knock at the door from Grot anytime soon, but we could just find out that it's a much more messy, contaminated universe than we ever thought, and that would be exciting.

Right: Where will alien microbes be found first: Venus or Mars?



Is There Anybody Out There?

After the success of his previous two books, *Beyond the Sky* and *Secret Science*, Ó Briain has now added a highly anticipated third instalment. This book takes the reader through the formation of planets, the search for life and whether aliens are soon to be found.



© Scholastic UK

Right: Comet NEOWISE was the target of many photographers in 2020



Source: Wikipedia Commons © Kalpa Semasinghe

WHAT WE LEARNED FROM THE CHALLENGER DISASTER

© NASA, Getty



The first loss of a Space Shuttle and its crew was a preventable disaster, but it would go onto largely change NASA for the better

Reported by Ian Evenden

Just 73 seconds was all it took from the launch of Space Shuttle mission STS-51-L on 28 January 1986 to the Shuttle's disintegration over the Atlantic and the loss of all seven of its crew. It was a routine mission to deploy a data relay satellite and test a probe designed to observe Halley's Comet, but was notable for the presence of Christa McAuliffe - the first teacher in space, and a civilian, in the crew. She had been chosen for the mission out of an initial application pool of more than 11,000, and was planning to carry out experiments and beam back lessons to Earth in order to rekindle interest in the US space program, remind Americans of the role teachers play in society and demonstrate the reliability of spaceflight.

Challenger was completely destroyed in the disaster, which was traced to the failure of an O-ring seal in the Shuttle's right-hand solid rocket booster. This allowed hot gases to flare out, burning through the strut attaching the booster to the external fuel tank and causing the two to clash together, eventually leading to structural failure of the fuel tank and allowing all parts of the launch vehicle to fly apart, disintegrating under the pressure of aerodynamic forces.

It's not a long time, but it's possible for a great deal to happen in such a compressed period. Those 73 seconds led to an investigation that took months to complete its analysis, and a total shutdown of the Shuttle program for 32 months. The morning of 28 January had been cold, and ice had formed on the launch pad at Kennedy Space Center, Florida. Challenger's launch was delayed by two hours to allow the ice to melt, but this wasn't the first delay to the mission. Originally scheduled for July 1985, STS-51-L was to be the 25th Shuttle mission, and the tenth flight of Challenger. Delays put the launch back to November. A Columbia

mission scheduled to go up just before Challenger was also delayed, pushing the mission back even further to 22 January 1986, then 25 January. Bad weather set in, and the launch was rescheduled for 27 January, then finally 28 January after a problem with a hatch handle.

Engineers were worried that the amount of ice present on the pad could damage the Shuttle at liftoff, perhaps striking the Shuttle's thermal protection tiles. The temperature on the morning of launch was as low as -2.2 degrees Celsius (28 degrees Fahrenheit) - the minimum required for a launch was -1 degrees Celsius (30.2 degrees Fahrenheit), and the previous coldest launch had been at 12 degrees Celsius (53.6 degrees Fahrenheit). But despite managers at the launch pad voicing their concerns, the mission manager in Houston, Texas, gave clearance to launch after a final inspection showed the ice to be melting.

The Shuttle wasn't certified to operate in temperatures that low, and concerns had already been raised about the O-rings. The solid rocket boosters were constructed in sections, which were joined together at the Kennedy Space Center prior to launch. Each joint was sealed with two rubber rings to prevent the hot gas from the burning propellant going the wrong way up the booster, instead being forced out the nozzle at the bottom. A 1971 report had discussed a possible

THE CASUALTIES



Francis Richard Scobee
Commander



Michael John Smith
Pilot



Ellison Shoji Onizuka
Mission specialist



Judith Arlene Resnik
Mission specialist



Ronald Erwin McNair
Mission specialist



Gregory Bruce Jarvis
Payload specialist



Sharon Christa McAuliffe
Teacher and payload specialist

All headshots © NASA

MINUTE BY MINUTE

WHAT HAPPENED DURING THE CHALLENGER DISASTER?

The disaster was over quickly; but a lot happened in those 73 fatal seconds

1 BLASTOFF

T+0.00s

As the command to ignite the solid fuel rockets is sent, mission specialist Judith Resnik can be heard to say, "All Right!"

2 BLACK SMOKE

T+0.678s

Smoke from just above the O-ring in Challenger's right-hand booster is captured on film, but not seen until it is developed.

3 THROTTLE UP

T+4.364s

The main engine throttle is increased from 90 per cent to 104 per cent, as planned.

4 THROTTLE BACK

T+19.885

Commands are sent to the main engines to throttle down to 94 per cent.

5 HIGH AND FAST

T+28.000

The Shuttle reaches 3,050 metres (10,000 feet) in altitude and half the speed of sound.

6 SUPERSONIC

T+40.000

At almost 6,100 metres (20,000 feet), Challenger breaks the sound barrier. Engines throttle down to 65 per cent.

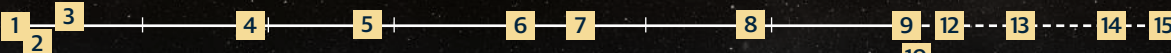
7 FLASHES

T+45.217

A flash is observed behind the Shuttle's right wing, followed by two more three seconds after the first.

O-RING FAILURE

The O-ring seals - not designed to handle cold conditions - failed and allowed hot, pressurised gas to burn through the skin of the booster, severing its connection to the external fuel tank and leading to structural failure.



8 FLAMES SEEN

T+59.753

Flames can be seen on the side of the right-hand booster. A plume of exhaust can also be seen by tracking cameras on the booster.

9 O-RING FAILURE

T+72.284

The right-hand booster pulls away from the strut that connects its base to the external fuel tank. A large ball of fire appears.

10 FINAL TRANSMISSION

T+73.000

Over the intercom, pilot Michael J. Smith says, "Uh-oh".

11 FIREBALL

T+73.191

Cameras record a brilliant flash as Challenger is engulfed in yellow and red flames.

12 BREAK UP

T+74.587

Another flash as, travelling at twice the speed of sound, Challenger disintegrates in flight. The last of the propellant in the external tank ignites, leaving the two solid rocket boosters to continue climbing.

13 RIGHT BOOSTER DETONATED

T+110.250

Safety officers signal the self-destruct packages in the boosters to detonate.

14 CABIN DOWN

T+3 min 58 sec

The crew cabin hits the Atlantic Ocean, subjecting the crew to a force of 200G. It disintegrates and debris sinks to the bottom.

15 DEBRIS

T+5 min 36 sec

The final large piece, thought to be one of Challenger's wings, splashes into the ocean. Small pieces of debris continue to fall for some time.



booster failure caused by hot gas burning through "adjacent to [liquid hydrogen/oxygen] tank or orbiter," and warning that "timely sensing may not be feasible and abort not possible". It wasn't unknown for the O-ring seals to bend, opening a hole through which hot gas could escape, eroding the surface of the ring thanks to the drop in pressure - a 1977 test managed to do it using just pressurised water - but despite the concerns of engineers, including a letter to the manager of the Solid Rocket Booster project, the boosters were approved for flight in 1980.

STS-2, the second Shuttle mission, showed serious erosion of the O-rings. The seals were redesignated as a Criticality 1 part, meaning their failure could result in the destruction of the orbiter, but the design wasn't changed. Damage to O-rings on subsequent flights was labelled an 'acceptable risk', even when seven of the nine Shuttle flights in 1985 showed such damage. It was a previous Challenger mission, STS-51-B in April 1985, that finally saw the design change process begin, because the primary O-ring on the left-hand booster was damaged so severely that for the first time the secondary ring was damaged too.

Additional steel was added around the seal, but the redesigned steel cases were still in production at the time of the Challenger disaster. "Today," wrote a *New York Times* report at the time, "they are the basis for the creation of improved boosters. [But] did officials who knew about these casings press to continue flights? Why was the new design being applied slowly?"

These are, of course, excellent questions, but the Rogers Commission, set up by President Reagan to investigate the disaster, steered away from them, its chairman William P. Rogers stating that the panel should deal only with events leading directly

"DESPITE THE CONCERNS OF ENGINEERS, THE BOOSTERS WERE APPROVED FOR FLIGHT IN 1980"

to the disaster. The commission - which included the first man on the Moon Neil Armstrong; physicist Richard Feynman, who'd worked on the Manhattan Project; astronaut Sally Ride, who'd flown twice on Challenger and the first man to break the sound barrier, Chuck Yeager, among other Air Force personnel, aeronautics experts, scientists and engineers - would, however, be strongly critical.

The commission found that NASA had known about the problem with the O-rings - and their potential for calamity - as early as 1977. Both NASA and its contractor, Morton-Thiokol, had failed to respond adequately to the design flaw. The commission described the disaster as "an accident rooted in history," criticising the decision-making process that had led to the launch of the Shuttle

that icy morning. It was "based on incomplete and sometimes misleading information," the report states, and that "NASA management structure ... permitted internal flight-safety problems to bypass key Shuttle managers."

Richard Feynman was an outspoken member of the commission, investigating in his own style and annoying Rogers to the extent that he called the physicist "a real pain". In a televised hearing, Feynman produced some of the O-ring material and dunked it in iced water, demonstrating for the cameras how it became rigid and more prone to failure when it was chilled. "I discovered that when you put some pressure on it for a while and then undo it, it does not stretch back," he said. "There is no resilience in this particular material when it is at a temperature of 32 degrees Fahrenheit [0 degrees Celsius]."

When not utilising props to devastating effect, his interviews with NASA officials demonstrated that basic safety terminology was being misunderstood, and that the probabilities of failure generated by the agency were far from accurate. Taking the example of NASA's claimed 1 in 100,000 chance of a catastrophic failure of a Shuttle, he realised this meant they could be launched for 274 years and expect only one incident. NASA had used these inaccurate figures to persuade McAuliffe to join the mission, and Feynman felt that the recruitment of civilians required honesty about the risks of spaceflight.

A 2013 film, *The Challenger*, revealed astronaut Sally Ride had secretly provided a commission member, General Donald Kutyna, with NASA test results showing the effect of cold on the O-rings. Kutyna was then able to point Feynman in the right direction, asking him an apparently innocuous question about temperature's effect on the seals in a car carburettor that sparked the



Above: A joint that retained traces of O-ring seal tracks. Samples of the track material underwent chemical analysis that indicated that they were not composed of degraded O-ring seal material

Left: Challenger sits atop the crawler-transporter on its way to the launch pad

CHALLENGER BY THE NUMBERS

SEVEN

members of crew – six
astronauts and one civilian

143,000

gallons of liquid oxygen plus
383,000 gallons of liquid
hydrogen in the external
fuel tank

20X

more fuel by weight than the
Shuttle itself

56.1

metres from the rocket
motor nozzles to
the nosecone

1977

First approach and
landing tests of the
Enterprise prototype

135

Total number of
Shuttle missions

TWO

major disasters resulting in
the loss of crew

2011

Final Shuttle mission,
STS-135, to the ISS

“FOR A SUCCESSFUL TECHNOLOGY, REALITY MUST TAKE PRECEDENCE OVER PUBLIC RELATIONS”

RICHARD FEYNMAN

physicist's imagination. “Sally and I were really good buddies,” he told *Popular Mechanics* in 2016. “She figured she could trust me to give me that piece of paper and not implicate her or the people at NASA who gave it to her, because they could all get fired. I wondered how I could introduce this information. I kept it a secret that she had given me that piece of paper until she died.”

The commission concluded that the disaster was an internal NASA matter, and that the agency could be left to address it with no need for a reduction in funding or a grounding of the Shuttle fleet. Feynman was so angered by this that his dissenting opinion was almost dropped from the report, eventually appearing as an appendix to the main body. He raged against NASA management, writing: “It appears that there are enormous differences of opinion as to the probability of a failure with loss of vehicle and of human life. The higher figures come from the working engineers, and the very low figures from management.

“For a successful technology,” he concluded, “reality must take precedence over public relations, for nature cannot be fooled.” He would go on to suggest he had been led to the damning evidence by either NASA personnel or contractors. A second report into the disaster – carried out by the US House Committee on Science and Technology in late 1986 – agreed broadly with Rogers, but placed the blame on “poor technical decision making over a period of several years by top NASA and contractor personnel, who failed to act decisively to solve the increasingly serious anomalies in the Solid Rocket Booster joints”.

In response to the Rogers Commission's report, with its nine safety recommendations, NASA began a complete redesign of the Shuttle's solid rocket boosters, overseen by an independent review body. The launch schedule was reorganised to give more time between launches, and a new orbiter, Endeavour, was commissioned to replace Challenger. It was decided that expendable launch vehicles, rather than crewed Shuttles, would be used for commercial satellite deployment missions. After 32 months grounded, the next Shuttle mission – STS-26 using Discovery to deploy a data relay satellite – returned safely to Earth after four days in space in October 1988.

Many lessons were learned from the Challenger disaster, but it's telling that the report into the second Shuttle crash, that of Columbia in 2003, would conclude that NASA had failed to learn many of the lessons of Challenger. While the agency had set up an independent office for safety

Below:
Challenger
fuselage
display at
the Kennedy
Space Center
Visitor
Complex



oversight as directed by the Rogers Commission, it did not meet the commission's intentions, and that decision making within NASA was still flawed.

The inclusion of McAuliffe on the crew, combined with the TV-friendly timing of the launch, meant that media coverage of the Challenger disaster was extensive, with many children watching the events play out. It's estimated that up to 17 per cent of the US population witnessed the disaster live on television, while 85 per cent knew about it within an hour. While NASA ended the program that saw civilians fly on Shuttle missions, Barbara Morgan, who was selected as McAuliffe's back-up on the Challenger mission, joined NASA and flew aboard Endeavour on the STS-118 mission to the International Space Station in 2007 as a mission specialist. She believes that despite the disaster, spaceflight is a worthwhile undertaking.

"Both Challenger and the Columbia have caused me to think, and it caused all of NASA to think," she said before the mission. "Kids were watching to see what the adults do in a terrible, terrible situation. What I thought was really important for kids to see is that we figure out what's wrong, we fix it and we move on, and we keep the future open for our young people."



Ian Evenden
Space science writer

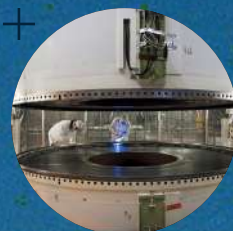
Ian has been writing about the universe for over ten years, focusing on cosmology and space exploration. He's also a keen astrophotographer.

Below:
Space Shuttle Challenger's STS-7 mission landed on 24 June 1983 at Edwards Air Force Base

Below:
Debris from the forward skirt of Challenger's Solid Rocket Booster

LESSONS NASA LEARNED

One thing was clear following the Challenger disaster: crewed spaceflight could not stay the same



NEW JOINTS AND SEALING SYSTEM

Redesigned joints - which were already in production - and a new sealing system were implemented, with an inspection regime, in time for the next flight. This also added a third O-ring, and heaters to the joints.



SAFETY, RELIABILITY AND QUALITY ASSURANCE

The establishment of a new SR&QA office to oversee flight safety, though this did not go far enough to satisfy the Rogers Commission. The office reported directly to the NASA administrator.



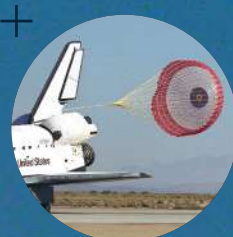
CREW ESCAPE SYSTEM

The Crew Escape System was provided following the Challenger disaster. Previously the crew had no way of escaping their compartment. However, as the later Columbia disaster showed, it was only effective during level gliding flight.



FLIGHT RATE CHANGES

Commercial pressures had led to a Space Shuttle mission launch rate described as 'optimistic'. The removal of commercial satellite launch duties from the Shuttle program meant fewer Shuttle missions could be launched, with larger gaps between.



LANDING SAFETY

The final Challenger mission may never have landed, but among the recommendations of the Rogers Commission was an overhaul of the landing system, particularly in the brakes and nose wheel steering system, as well as the drag parachute that aided braking.



REORGANISATION OF NASA MANAGEMENT

The post of chief engineer was absorbed into the SR&QA office, while a new flight safety panel was established to set firmly defined policies and procedures that would ensure the uniform application of standards throughout the agency.

CHANGES IN DECISION MAKING

Following criticisms from the Rogers Commission, changes were made to the way decisions were made at NASA, with managers at Houston no longer able to waive safety concerns in Florida.

SPACEFLIGHT NO LONGER SEEN AS ROUTINE

America was almost bored with spaceflight in 1986, and this is part of what prompted McAuliffe to be on the Challenger mission. The representation of Shuttle missions needed to be changed to better represent the danger astronauts put themselves in.



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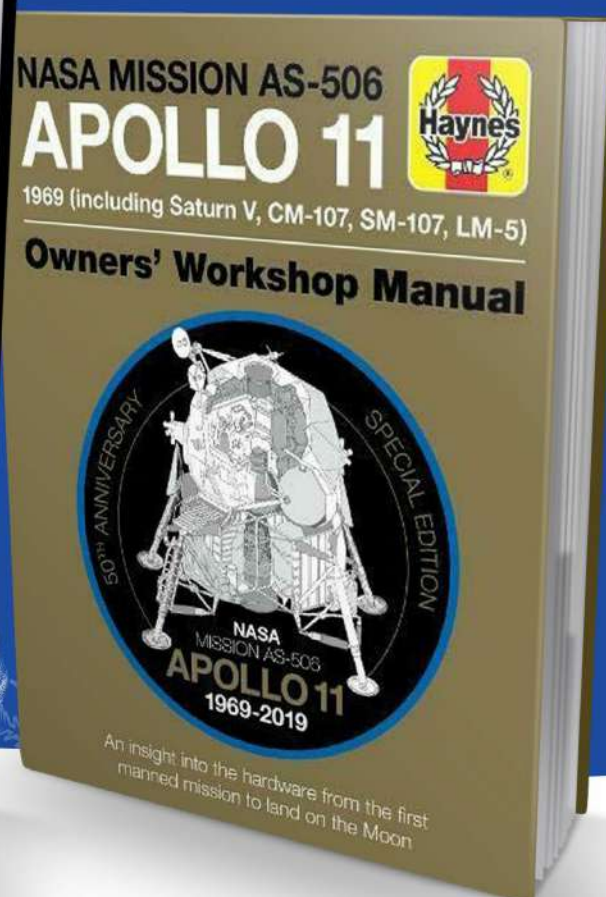
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61 CYGNI

THE STAR THAT CHANGED EVERYTHING

In the newly released *History of the Universe in 21 Stars (and 3 Imposters)*, the star 61 Cygni has been revealed to be the smoking gun in our understanding of the cosmos

Written by Giles Sparrow

Step outside and take a look at the early evening sky at this time of year and the constellation of Cygnus, the Swan, is hard to miss. This prominent cross-shaped constellation hangs high overhead, looking like a swan with outstretched wings and a long neck stretching along the Milky Way towards the southern horizon. The bright-blue star Deneb marks the Swan's tail high in the sky - the upper-left corner of the famous northern 'Summer Triangle' - while binoculars show that Albireo, on the tip of its beak, is a beautiful double star.

Cygnus is packed with beautiful and fascinating objects, so it's easy to overlook 61 Cygni, an apparently insignificant star tucked behind the Swan's right or eastern wing. But it's worth a look, not only because binoculars will show it as an attractive double star - a pair of yellow-orange stars separated by roughly the same diameter of Saturn in Earth's skies - but also because of its pivotal role in the history of astronomy. Out of all the stars in the sky, 61 Cygni was the first one to have its distance precisely measured, proving conclusively that the stars are blazing objects like our own Sun seen over vast distances.

Ancient and medieval astronomers mostly believed in an Earth-centred model of the universe - a system with Earth sitting at the centre of the cosmos, orbited by the Moon, Sun and planets, with the stars as either tiny lights affixed to an outer, all-encompassing sphere, or holes in that sphere permitting light to shine through from beyond. In general the universe was assumed to be compact, with the stars not much further beyond Saturn, then the most distant and slowest moving planet.

This view was shattered in the early 17th century. Early telescope observations by Galileo and others revealed moons orbiting Jupiter - conclusive proof that not everything in the universe circled the Sun - while Johannes Kepler made the theoretical breakthrough that orbits were usually ellipses rather than perfect circles. Together these discoveries backed up the idea of a Sun-centred or heliocentric universe, which had been on the table since Polish priest Nicolaus Copernicus published his controversial book *On the Revolutions of the Heavenly Spheres* from his deathbed in 1543.

One of several quite reasonable objections to the idea of Earth moving around the Sun was why our changing point of view didn't affect the positions of the stars through the year. Surely if our point of view looking towards distant stars was changing by tens of millions of miles over the course of a year, the stars should appear to move back and forth due to the same effect that makes objects near at hand shift their apparent direction when seen from two slightly different viewpoints, called parallax. Most astronomers reconciled the evidence by concluding

Below: The near-twin stars of 61 Cygni race across the sky, revealing their proximity to Earth

that the stars must lie at truly vast distances from Earth - so far away that parallax was undetectable to the simple telescopes of the time.

Nevertheless, the quest to measure parallax became a major preoccupation for astronomers over almost two centuries. It was seen as a door through which the scale of the universe itself could be revealed - but how did the search for a star with a detectable shift zero in on the obscure 61 Cygni?

The star first drew attention to itself when its double nature was spotted by Astronomer Royal James Bradley from the Royal Observatory at

WHERE IS 61 CYGNI?

Use our chart to find your way to the Flying Star

1 Northern Cross

Although usually thought of as a summer constellation, Cygnus is high overhead after sunset until well into the autumn - look for a distinctive cross shape in the southern sky.

4 Finding 61 Cygni

Look behind the Swan's outstretched eastern wing for a triangle of moderately bright stars - Zeta, Nu and Tau Cygni. 61 is halfway along the line between Nu and Tau.

2 Down the way

The short end of the cross of Cygnus represents its tail, while the long outstretched neck points south down the Milky Way, with 'wings' extended to either side.

3 Great Rift

Under dark skies or with binoculars, you should notice a long, dark 'gap' in the Milky Way extending from the south into Cygnus. This is the Great Rift - a dust cloud blocking the light from distant stars.

5 Deneb

The brightest star in Cygnus, Deneb marks the Swan's tail feathers. It's a blue-white supergiant star at least 50,000 times more luminous than our Sun.

"CYGNUS IS PACKED WITH BEAUTIFUL AND FASCINATING OBJECTS, SO IT'S EASY TO OVERLOOK 61 CYGNI, AN APPARENTLY INSIGNIFICANT STAR"

Source: Wikipedia Commons © IndividusObservans

61 CYGNI: THE FLYING STAR

61 Cygni is an unremarkable star system – if not for its proximity to Earth

Flying through the heavens

The twin stars of 61 Cygni first drew attention to themselves because of their high proper motion against more distant background stars – they move across the sky at a rate equivalent to the width of a full Moon every 464 years.

Heavenly pair

The two stars orbit each other in around 680 years, and are currently separated by 18 seconds of arc – about the width of Saturn as seen from Earth – and so can be distinguished from each other using binoculars or a small telescope.

Twin suns

Both stars in the system are orange dwarfs – stars less massive than the Sun at about 0.7 and 0.6 solar masses and shining with 15 and 8 per cent of its light output.

Telltale wobble

Around 11.4 light years from our Solar System, the two stars are close enough to shift slightly back and forth when viewed from different points on Earth's orbit. This shift amounts to a parallax angle of 0.285 arc seconds on either side of their central point.

Above: The ESA's Gaia spacecraft has provided accurate measurements from above Earth

Greenwich in September 1753. Over the following decades the stars were occasionally visited by astronomers keen to investigate the nature of such close pairs, but it was not until 1792 that Italy's Giuseppe Piazzi, a Catholic priest whose recently founded Palermo Observatory incorporated state-of-the-art equipment for measuring stellar positions, noticed something strange: the two stars had shifted position, and now lay slightly but unmistakably northeast of the location first reported by Bradley.

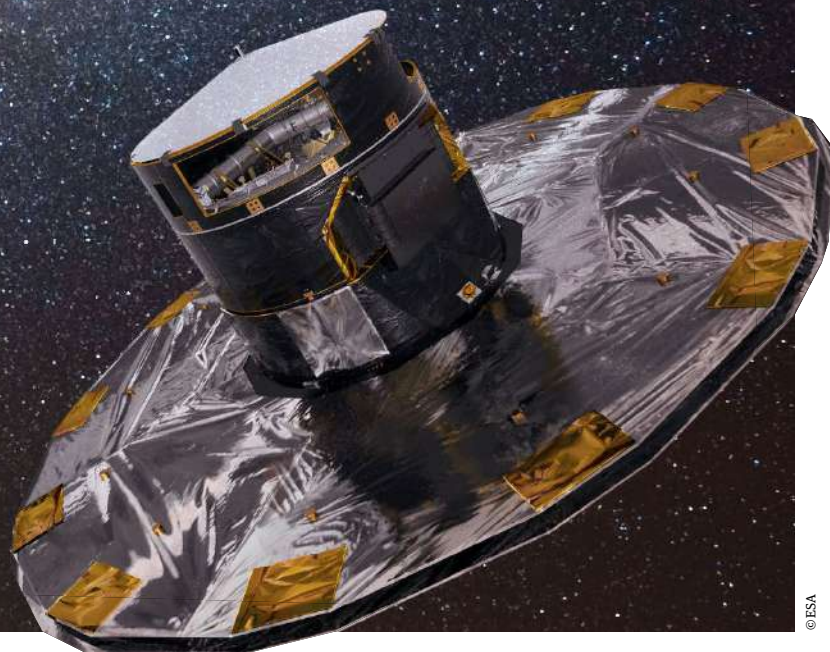
At the time Piazzi made a note of this unusual drift through the sky, a phenomenon that astronomers call 'proper motion', but he did not confirm it until 1804, when he revisited the star while compiling a detailed stellar catalogue. In the intervening years Piazzi had found fame through his discovery of Ceres, the largest asteroid and the first object to be discovered orbiting between Mars and Jupiter. Careful checking now confirmed his suspicion that 61 Cygni was moving across the sky at a surprisingly rapid rate of 4.1 seconds of

arc per year, equivalent to the width of an average full Moon every 464 years. After the catalogue was published in 1806, 61 Cygni soon garnered the nickname of 'Piazzi's Flying Star'.

Proper motion of the stars in Earth's skies is caused by a combination of their real drift through space and Earth's own drift as it is carried along with the Sun and the rest of the Solar System. Unlike the repeating back-and-forth drift expected from parallax, it manifests itself as a steady crawl in one particular direction across the sky, slowly rearranging the shapes of constellations over many thousands of years. With parallax itself still elusive, however, astronomers had realised that you could use proper motion as a neat proxy for a star's likely distance from Earth. Based on the reasonable assumption that stars travel at similar average speeds through space, then the closer the star is, the faster it will appear to move across the sky. 61 Cygni turned out to have the largest proper motion yet discovered, and was therefore immediately recognised as one of the closest stars to Earth. This made it a perfect target for ongoing attempts to measure our shifting cosmic point of view.

Even by the early 19th century, however, the challenge of detecting a star's parallax remained a daunting one, involving precise measurement of distances less than one second of arc or 1/3,600th of a degree. To accurately measure these tiny shifts, early parallax hunters had to battle not only the relatively primitive quality and low power of their telescopes, but also the effects of the atmosphere blurring the sharpness of star images – and even

“OUT OF ALL THE STARS,
61 CYGNI WAS THE FIRST
ONE TO HAVE ITS DISTANCE
PRECISELY MEASURED”



© ESA

the simple difficulty of knowing where, in terms of precise direction in the sky, their telescopes were actually pointing.

Early attempts at finding a solution therefore employed some ingenious lateral thinking. Bradley, for instance, long before his encounter with 61 Cygni, figured out a way to test the parallax of a moderately bright star called Eltanin, or Gamma Draconis. His approach measured the angle between Eltanin and the zenith – the point directly overhead – with pinpoint accuracy at the exact moment the star crossed the north-south line across the sky, so that he could be certain of Eltanin's precise position.

Bradley chose Eltanin because it passes almost directly overhead from London, helping to minimise another troublesome effect we haven't even mentioned yet – atmospheric refraction. As if the parallax quest didn't throw up enough challenges, astronomers also have to deal with the fact that as well as rippling and blurring the light from stars, Earth's atmosphere also deflects light rays onto new paths. The effect is strongly linked to the altitude at which a star appears in the sky, and

so Bradley and his collaborator Samuel Molyneux decided to avoid the issue as much as possible by looking at an object almost directly overhead.

When Bradley and Molyneux began measuring Eltanin's position in December 1725, they soon found that the star was moving. But from the outset the results were puzzling: Eltanin was moving southwards at a time when parallax should have already put it at its southernmost point in the sky. By March its motion finally slowed and reversed, and it then tracked northwards until September when it reversed again. Two more years of observation confirmed the turning points were consistently three months out, with Eltanin always switching direction in March and September rather than June and December as predicted.

Bradley soon realised that they had discovered an entirely unconnected piece of evidence for Earth's motion – an effect known as aberration of starlight. This is a change in the angle at which starlight approaches Earth due to our motion around the Sun – if you think about raindrops falling at a steady angle while you stand still, and then imagine how their angle changes when you're walking in

different directions, you'll get the picture. Because Earth's axis in space points in a constant direction as we make our annual trip around the Sun, the angle at which starlight falls towards Earth changes slightly in spring and autumn.

The complexities of aberration added further burdens to the already-difficult task of measuring parallax, but astronomers are a persistent breed, and thus the search continued throughout the 18th century and into the 19th, occasionally enlivened by triumphant announcements, nitpicking rebuttals and embarrassed retractions. It was not until the 1830s, however, that improved technology and skilful observing finally delivered an irrefutable parallax measurement.

In the end the race came down to two of the 19th century's finest observers: Friedrich von Struve and Friedrich Wilhelm Bessel. Both benefited from the fact that by this time clockwork-driven telescope mounts could be used to keep pace with the sky's apparent rotation and stop their target stars rapidly drifting out of view under high magnifications. And both also followed a suggestion first made by William Herschel in the 1780s – that the best

EXTENSIONS OF PARALLAX

The 'annual parallax' method used by Bessel to measure nearby stars paved the way for other ingenious methods of distance measurement. Statistical parallax uses the proper motions of stars as a direct distance indicator on the assumption that, on average, more distant stars will move more slowly through the sky. Dynamical parallax calculates the size of the orbit in a binary star system and compares that to the stars' measured separation in the sky. Cluster parallax methods use various tricks to guess the size or average proper motion of distant star clusters and therefore estimate their distance.

ALL ABOUT PARALLAX

Using simple geometry, parallax measurements reveal the distance to the stars

2 Parallax shifts

Nearby stars appear to shift their positions in the sky by a larger angle than more distant stars. Parallax shifts can be measured relative to more distant unshifting stars or on the fixed grid of celestial coordinates.

3 Tiny angles

The parallax shifts of even the closest stars are mere fractions of an arc second. Detecting them requires high-precision measuring instruments. Other clues, such as rapid 'proper motion' of nearby stars, suggest where to look.

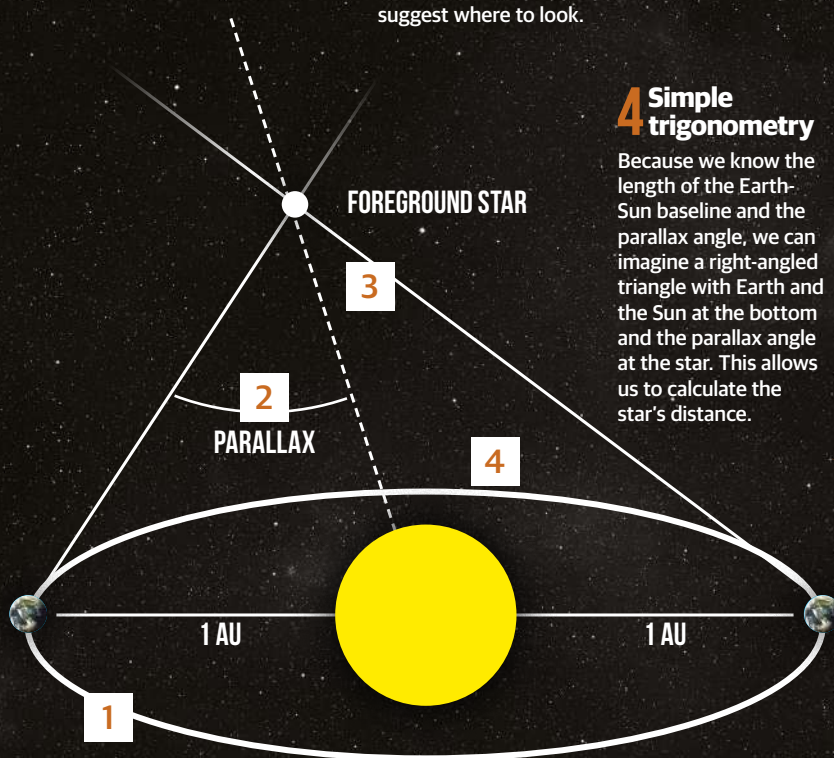
BACKGROUND STARS

4 Simple trigonometry

Because we know the length of the Earth-Sun baseline and the parallax angle, we can imagine a right-angled triangle with Earth and the Sun at the bottom and the parallax angle at the star. This allows us to calculate the star's distance.

1 Earth's orbit

As Earth orbits the Sun during the course of a year, it moves around a circle with a diameter of 300 million kilometres (186 million miles). This creates a slight shift in our view of the surrounding universe.



TIMELINE OF THE DISCOVERY OF 61 CYGNI

1543 THE COPERNICAN REVOLUTION

Copernicus published his influential argument that the Sun is at the centre of the Solar System. As evidence to support this idea mounted, astronomers hoped to clinch the argument by discovering stellar parallax. When they didn't, they concluded that the stars must be very far away.



1718 PROPER MOTION

Halley reported evidence that the positions of certain bright stars had shifted significantly since they were catalogued by ancient Greek astronomers. This was the first sign of proper motion - the slow rearrangement of the stars in Earth's skies due to their motion through space.



1727 ABERRATION OF STARLIGHT

While attempting to measure the parallax of the star Eltanin in Draco, Bradley discovered a shift in the apparent positions of all stars throughout the year caused by aberration of starlight - changes in the angle at which light approaches Earth caused by our motion through space.



1804 A FLYING STAR

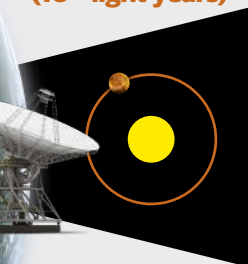
Giuseppe Piazzi confirmed his earlier suspicion that 61 Cygni, the double star in Cygnus first reported by Bradley half a century earlier - has a very high proper motion of 4.1 seconds of arc per year, suggesting it is nearby and a potential target for parallax measurements.



THE COSMIC DISTANCE LADDER

How do we work out distances as they increase across the vastness of space?

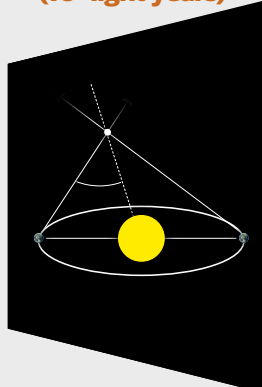
Solar System (10^{-4} light years)



Inside the Solar System

Accurate measurements of the distances to neighbouring planets can be made by measuring the time for radar signals to bounce off the planets' surfaces and return. Combined with models of planetary orbits, these provide an accurate scale for the Solar System.

Nearby stars (10^2 light years)



Nearby stars

Annual parallax and related tricks can be used to find accurate distances to nearby stars. Satellites such as Hipparcos and Gaia have extended annual parallax measurements to much greater distances.

Milky Way (10^5 light years)



The Milky Way

Once parallax measurements confirmed the true luminosity of some stars, clear relationships began to emerge between luminosity and spectral features such as a star's colour. Using a star's spectrum to estimate its inherent luminosity, astronomers can then make an educated guess at its likely distance.

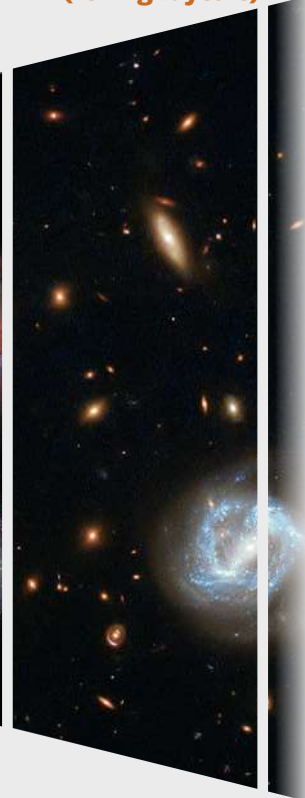
Nearby galaxies (10^7 light years)



Nearby galaxies

Several types of variable star display a relationship between the period of their pulsations and their true average luminosity. The most useful of these are brilliant yellowish stars called Cepheid variables. Measuring the periods of Cepheids in nearby galaxies reveals their distance.

Galaxy clusters (10^{10} light years)



The distant universe

Type Ia supernovae are a form of exploding star that always peak at the same luminosity. Though infrequent, they can give a rare clue to the distance of the most remote galaxies. Astronomers also use a statistical trick called the Tully-Fisher relation, which estimates the typical luminosity of certain galaxies within clusters.

"THE STARS WERE TRANSFORMED INTO DISTANT BUT MEASURABLE OBJECTS"

1837 RACING FOR PARALLAX

Friedrich von Struve published an accurate preliminary estimate of parallax for the bright star Vega, or Alpha Lyrae, but continuing observations eventually led him to a larger and less accurate final figure by 1840. His original figure was very close to modern-day calculations.

**1838 BESSEL'S TRIUMPH**

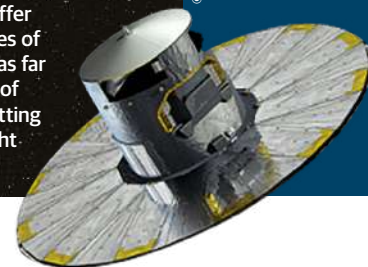
Friedrich Bessel completed his parallax measurements of 61 Cygni, demonstrating its annual parallax of 0.314 seconds of arc and indicating a distance of around 10.3 light years – ten per cent below current estimates. He also worked out the orbital period of the binary pair.

**1913 THE HERTZSPRUNG-RUSSELL DIAGRAM**

Building on earlier work by Danish chemist and astronomer Ejnar Hertzsprung, American astronomer Henry Norris Russell used the parallax of nearby stars to plot a diagram comparing their true luminosity with their colour or 'spectral type'. The diagram reveals patterns in the properties of stars that prove to be the key to understanding stellar evolution.

2013 MEASURING THE MILKY WAY

The European Space Agency launched Gaia, an advanced satellite designed to carry out a decade-long parallax survey in unprecedented detail. Gaia's measurements offer accurate estimates of stellar distances as far off as the centre of the Milky Way, sitting some 26,000 light years away.



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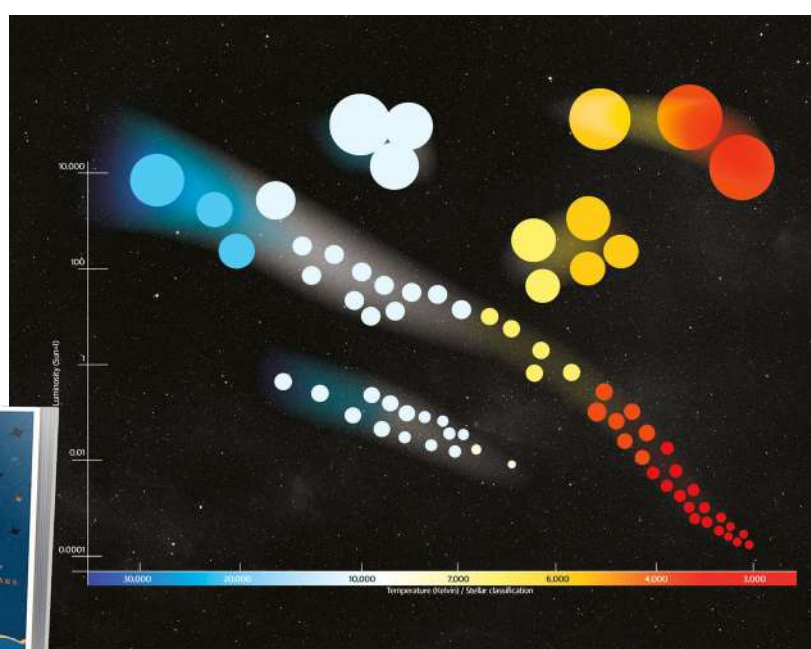
approach was to look for changes in a target star's position relative to others that lay nearby in the sky rather than trying to track its precise location on the celestial sphere.

Struve's effort focused on Vega, among the brightest and best known of all stars, while Bessel concentrated on the far more obscure 61 Cygni. As it turns out, Vega is about twice as far away as 61 Cygni, and has slightly less than half the parallax, making Struve's task considerably more difficult. Struve was also using a traditional 'micrometer' eyepiece – a design in which two fine parallel wires are projected into the observer's field of view. The separation between these wires can be changed very gradually by turning an adjustment screw, and you can then translate the distance between the wires into an angular separation in the sky with some fairly simple maths. Struve began to track Vega's relative motion in late 1835, and by 1837 he had 17 measurements that allowed him to publish a preliminary figure for Vega's parallax of one-eighth of a second of arc – close to the modern value. Had he stopped there he might perhaps have claimed the prize, but instead he continued, and by 1840, when he published his final result, his estimate had doubled, putting it far adrift of later measurements.

Bessel, in contrast, used a different sort of set-up known as a heliometer. This was a refracting lens-based telescope whose main or objective lens was carefully cut into two halves. The separation produced a double image in the eyepiece, and one half-lens could be finely adjusted with a screw system so that when the images of two separate stars overlapped, the heliometer revealed the angular separation between them. Beginning in August 1837, Bessel managed to take 98 parallax measurements of 61 Cygni over just 13 months. He quickly processed his data and published his results by way of a letter to Sir John Herschel, now president of the Royal Astronomical Society in London, on 23 October 1838.

Right: The Hertzsprung-Russell diagram plots magnitude against spectral types

Below: Discover more about the stars in Giles Sparrow's new book



Bessel's calculations were a tour de force, and far more convincing than Struve's more limited data. He not only estimated the parallax of the overall 61 Cygni system as 0.314 seconds of arc – equivalent to a distance of 10.3 light years – but also analysed the relative motions of the two stars and showed that they took at least 540 years to orbit each other. These figures stand up remarkably well even today, where the system's parallax has been refined to 0.286 arcseconds, its distance to 11.4 light years and its orbital period to around 678 years.

Herschel referred to Bessel's measurements as the moment when the "sounding line in the universe of stars had at last touched bottom" – they marked the beginning of a new era in which stars were transformed from points of light in the sky into distant but measurable objects whose physical

properties can be analysed and understood. Even today when it is measured to amazing precision by orbiting satellites such as the European Space Agency's (ESA) Gaia, parallax remains our only method of directly measuring the distance to objects in the wider cosmos, and provides a happily stable first rung on a ladder of cosmic distances that gets increasingly rickety as it extends further from the certainties of Earth. We should all spare a thought for the obscure double star in Cygnus where it all began.

**Giles Sparrow**

Space science writer

The author of over 20 books on popular science, Giles holds a degree in astronomy and is an editor specialising in science and technology.

2021's unmissable space events

2021

UNMISSABLE SPACE EVENTS

2020 was an interesting space year, but 2021 promises to be even more exciting, with multiple Mars missions, James Webb and multiple new launchers and spacecraft

Reported by Robin Hague

NEW LAUNCHES

SPACE EXPLORATION

JANUARY

STARLINER ORBITAL FLIGHT

THE NEXT UNCREWED TEST OF BOEING'S CAPSULE

Though SpaceX has commenced commercial crew flights to the ISS in 2020, Boeing has also been building a new crew transport capsule. The Starliner made an initial uncrewed test in December 2019, but suffered a software fault that prevented it completing its flight to the ISS. After extensive software troubleshooting the Starliner will repeat the uncrewed launch to the ISS in early 2021. If all goes well a second Starliner should carry astronauts Nicole Mann, Mike Fincke and Barry Wilmore to the ISS as early as June, providing the US with a second independent human launch capability.



© NASA

JANUARY

LINKSPACE NEW LINE 1

CHINESE COMPANY PLANS FIRST SPACE-X LIKE REUSABLE LANDING

Though the international launch industry was bemused at best, and mostly dismissive of SpaceX's plan to land and reuse first stages, the company's great success in doing so has led many to begin work on similar vehicles. LinkSpace, a Chinese start-up company, looks set to be the first to fly a new vehicle following the powered first-stage landing approach. Given that China's launch sites are all inland, notoriously dropping spent stages near towns and villages, powered landing could be accomplished without needing to land on a floating pad, and increase safety for those downrange.



© Alamy

JANUARY

ASTRA ROCKET 3.0

NEXT ATTEMPT BY SMALL CALIFORNIAN COMPANY TO LAUNCH MICRO-LAUNCHER

Although it has not yet reached orbit, Astra is a well-established new launch vehicle company from San Francisco, only announcing its presence in 2020 to make an attempt on the DARPA launch prize. After two launch failures from its pad at Kodiak Island, Alaska, hopes are high that it will join the club of private orbital launchers on the next attempt.



© Astra

METEOR SHOWERS

3 JANUARY

QUADRANTIDS

The first shower of the year is better for the Northern Hemisphere given the latitude of their origin, and if you hit lucky with the weather it can produce some good fireball meteors.

6 MAY

AQUARIDS

The Aquarids originate from Halley's Comet and are expected to produce between 10 and 30 meteors an hour towards the end of the night.

12 AUGUST

PERSEIDS

The Perseids are the best known meteor shower, and in 2021 they will coincide with a new Moon, giving the best viewing conditions and potentially more than a meteor per minute.

14 DECEMBER

GEMINIDS

The Geminids are unusual in originating from an asteroid, 3200 Phaethon, which itself is an unusual colour for an asteroid - blue! A reliable shower, it is often worth looking for over a number of nights.

ECLIPSES

26 MAY

Total lunar eclipse
Pacific region

10 JUNE

Annular solar eclipse
Arctic region

18 NOVEMBER

Partial lunar eclipse
Siberia, the Pacific, North
America, Western Europe

4 DECEMBER

Total solar eclipse
Antarctica

© NASA

FEBRUARY

NURI

INITIAL LAUNCH OF
FIRST KOREAN SPACE
AGENCY LAUNCHER

Though the space industry is largely focused on private launch programs beginning to at last take flight, South Korea's national program is gearing up to launch its first indigenous launch vehicle Nuri after initial tests with the largely Russian-built Naro. Flying from Naro Space Center, it will make South Korea the ninth country to be able to launch its own space vehicles from its own territory.



11 FEBRUARY

TIANWEN-1: MISSION TO MARS

CHINA'S FIRST MARS MISSION WILL
ENTER MARTIAN ORBIT

Perseverance is not alone in this Mars mission window. Tianwen-1, or 'heavenly questions', China's first independent Mars mission, will place a spacecraft in orbit and a lander and rover on the surface to look for biosignatures. The mission blasted off successfully on 23 July 2020.

© CASC



© MBRS

FEBRUARY

EMIRATES MARS MISSION: HOPE

THE FIRST SPACE PROBE
FROM AN ARAB NATION

The third new arrival at Mars this window is the Hope orbiter from the United Arab Emirates Space Agency, itself only founded in 2014. Hope launched on 19 July 2020 and aims to study the Martian atmosphere and climate.

18 FEBRUARY

PERSEVERANCE MARS ROVER LANDING

NASA'S LATEST ROVER WILL ADD TO ITS
ROBOTIC RANKS ON THE RED PLANET

Get ready for another 'seven minutes of terror'. This was the description of Curiosity's audacious landing method back in 2011, where it was lowered onto the surface from a rocket-powered crane, and the new Perseverance rover is doing the same. NASA's new car-sized rover is building on the success of Curiosity: the structure is enhanced, the wheels strengthened and there's nearly a decade's development in sensors and computing. It weighs in slightly heavier than Curiosity, and it will look for signs of life, past or present. It is also carrying microphones to record the first-ever sampling of the sounds of Mars, though probably the most excitement will be generated by Ingenuity. Hitching a lift with Perseverance, Ingenuity is a tiny helicopter that will be released for the first powered flight on another world.



© NASA/JPL-Caltech

MARCH

BLUE WHALE

THE FIRST PLANNED LAUNCH OF PRIVATE SOUTH KOREAN NANO-LAUNCHER

South Korean company Perigee is hoping to open a whole new sector in the launch industry with its tiny - less than two tonnes at launch - Blue Whale vehicle, designed to orbit payloads of only 50 to 60 kilograms. It will be a big moment for Australia too, as the plan is to launch southwards over the Austral Ocean from a new Australian launch site at Whalers Way. This is the first orbital launch from Australia since Britain's Black Arrow rocket flew from Woomera in October 1971.



© Latamsatelite

© NASA

MARCH

FALCON HEAVIES

SPACE X BRINGS OUT THE BIG GUNS

Improvements made to the Falcon 9 rocket and its Merlin engines have meant SpaceX hasn't needed its Falcon Heavy as frequently as originally planned. But 2021 should see three of its famous synchronised double-side booster landings - truly a sight to behold as they land together.



JULY

FIRST FLIGHT OF ULA'S VULCAN CENTAUR

THIS NEW AMERICAN ROCKET WILL BE A SATELLITE-LAUNCHING POWERHOUSE

United Launch Alliance (ULA), long-standing operators of Delta and Atlas launch vehicles, will be launching another new American rocket, the Vulcan Centaur, around July. Significantly undercut by the arrival of SpaceX, the Vulcan is ULA's response to this challenge to cut costs.

JULY

ARIANE 6: THE NEW EUROPEAN ROCKET

A COST-SAVING UPGRADE TO ARIANE 5

This is Arianespace's attempt to dramatically cut launch costs over Ariane 5 in response to SpaceX, but the company is already looking at future reusable rockets beyond this. Ariane 6 should fly from Guiana Space Centre in the second half of 2021, potentially into 2022.

© ESA



Q3

STARSHIP ORBITAL LAUNCH

A BIG STEP IN FURTHERING SPACE EXPLORATION GOALS

SpaceX's Starship program has been moving at tremendous pace after Starships 5 and 6 took flight. Starships 8 and 9 - fitted with nose cones and flaps - are planned to make flights to progressively greater heights. Critical to SpaceX's plans for the vehicle is its flat-falling 'skydiver' re-entry, and this will be a focus of testing. Such is Starship's potential capability that a test ship without payload should be able to put itself into orbit in a single stage. If the initial hops go well, we should see such an orbital flight in 2021.



© Adrian Mann

Q3

SUPER HEAVY HOPS

SPACEX'S CHUNKY FIRST STAGE TO UNDERGO TESTING

While Starship is big, it is only the upper stage of SpaceX's complete new system. Following on from the rapid prototyping approach applied to Starship, bits of Super Heavy, its huge first stage, have already been seen appearing at the Boca Chica facility. Despite its scale, the mission profile is technically easier than Starship, being closer to Falcon 9-type landings. Sometime over 2021 we should see the 72-metre (236-foot) tall, nine-metre (29.5-foot) diameter stage starting its own program of hops.

© SpaceX



Q3

NEW GLENN FIRST LAUNCH

BLUE ORIGIN TAKES A BIG STEP UP FROM NEW SHEPARD

Jeff Bezos' Blue Origin plans to make its first orbital attempt, building upon the success of the New Shepard suborbital vehicle but going straight for a vehicle larger than Falcon 9 and nearly 5.5-times taller than New Shepard. It is a huge step, but Blue Origin is noted for slow and steady progress, and tends to hit deadlines. Gradatim Ferociter!

© Blue Origin



2 OCTOBER

BEPICOLOMBO REACHES MERCURY

THE CRAFT IS NEARING ITS TARGET

Launched back in October 2018, after using the gravity of Earth and Venus to speed up its long journey, the joint JAXA/ESA mission will make the first of several flybys of its target Mercury, working towards orbital insertion in 2025.



© Adrian Mann

31 OCTOBER

JAMES WEBB LAUNCH

WILL WE FINALLY SEE WEBB TAKE FLIGHT?

Of tremendous interest to both the space launch and astronomy communities, NASA's heavily delayed James Webb Space Telescope (JWST) is finally expected to launch in October, 13 years later than planned. The project started in 1996 as a successor to the Hubble Space Telescope, with a mirror more than seven-times larger. But this increase in scale necessitated a complex multi-segment mirror and folding Sun shield, leading to an increase in cost and time. Once launched it will dwarf Hubble's capabilities and revolutionise, among many strands of astronomy, the search for exoplanets. It is scheduled to finally hitch a lift with Europe's Ariane 5 rocket from Kourou in October.



© Adrian Mann

NOVEMBER

SPACE LAUNCH SYSTEM'S (SLS) FIRST LAUNCH

THE ROCKET THAT WILL TAKE HUMANS BACK TO THE MOON WILL UNDERGO TESTING

NASA's own monster rocket, many years delayed, is expected to finally launch in 2021. SLS started life as Ares V under President Bush's Constellation program to return to the Moon and fly to Mars. Based heavily on Space Shuttle technology, in large part to preserve the Space Shuttle's industrial base, it was cancelled between 2010 and 2014 before returning at the behest of the US Senate as the Space Launch System. It features four reused Space Shuttle main engines on the first stage, burning liquid oxygen and hydrogen, which will controversially be lost on each flight after completing multiple missions on the Shuttle. The rocket will stand roughly 112 metres (367 feet) tall, and launch will be assisted by two lengthened Shuttle-type solid boosters. With SpaceX and Blue Origin both making progress on heavy lifters, SLS may not survive long, but the first launch will likely happen, and will be the first Saturn V-size launch since Skylab in 1973.



© NASA

© NASA/SpaceX

Q4

FIRST CANADIAN ORBITAL LAUNCH

ANOTHER NATION REACHES FOR THE STARS

As more and more countries eye an orbital capability, Canada, a long-time spaceflight participant, is set to see its first launches starting in 2021. Maritime Launch Services is planning to offer commercial flights on Ukrainian Cyclone rockets from Nova Scotia, opening up another new access point to orbit.



© Maritime Launch Services

DECEMBER

SPACEX CREW DRAGON

SPACE IS BECOMING THE HOTTEST NEW TOURIST DESTINATION

From the start of its capsule program, SpaceX has proposed free-flying DragonLab missions, where its Dragon capsule would be used by itself, rather than as transport to the ISS. Now space tourism pioneers Space Adventures - responsible for Dennis Tito's first tourist trip to the ISS in 2001 - have bought a free-flying Dragon mission. It is planned to launch with four fare-paying passengers and operate autonomously in December 2021.



Robin Hague

Head of launch at Skyrora

After studying hybrid rocket engine design, Robin worked on propulsion for an XPRIZE entrant and has helped launch rockets from the UK.

MYSTERY SOLVED?

WHAT'S AT THE CENTRE OF JUPITER AND SATURN?

With the help of AI, planetary scientists may have finally been able to put an age-old puzzle to bed

Reported by Leo Bear-McGuinness

Of all the planets in our Solar System, Jupiter and Saturn are perhaps the most mischaracterised. Known as gas giants, many may naturally assume that these two behemoths consist of nothing but gas and clouds to their cores. While it's true that they mostly contain hydrogen and helium, these giants are much more than the Milky Way's two big balloons. Thanks to their phenomenal sizes, the planets accrue enough heat and pressure to compound their gases into liquid states. Under these unearthly conditions, helium and hydrogen flow in great seas just below the outer gaseous layers of the planets. Jupiter, the larger of the two giants, is thought to be home to the largest ocean in the Solar System – one made of pure hydrogen.

"Jupiter and Saturn are mostly made of hydrogen and helium, and this is the reason they are known as gas giant planets," says Ravit Helled, a professor in the department of astrophysics and cosmology at the University of Zürich. "However, the interiors

WHAT IS METALLIC HYDROGEN?

40,000

The estimated depth, in kilometres, of Jupiter's metallic hydrogen layer. This is equivalent to about 24,850 miles.

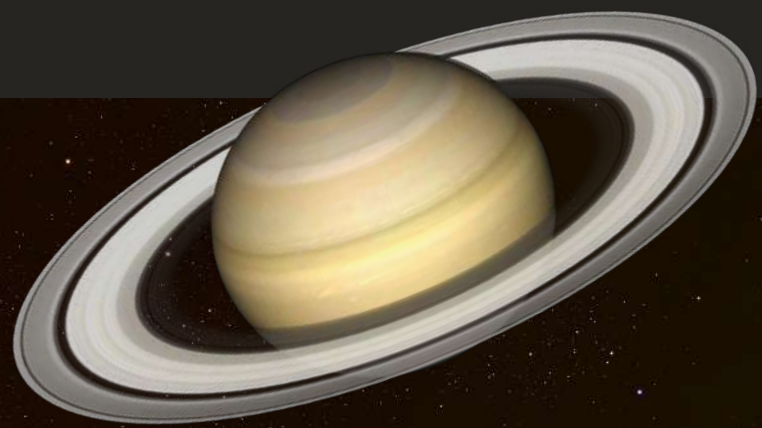
MORE HELIUM, LESS METAL

Helium stabilises the hydrogen molecules inside gas planets, delaying the onset of metallisation.

THE TRADITIONAL MIDDLE TIER.

In traditional models of gas planets, metallic hydrogen made up the inner layer. This distinction is now thought to be more fluid.

© NASA/JPL-Caltech





AN OLD IDEA

The metallisation of solid hydrogen was first predicted in 1935.

FIVE PHASES

Five non-metallic, solid phases of hydrogen have been identified so far, but more might be found in the future.

NOT SOLID PLANETS

Given their known conditions, it was thought that solid hydrogen couldn't be formed in the core of giant planets.

KEY TO MAGNETISM

Metallic hydrogen is thought to be the conducting material key to the gas planets' magnetic fields.

SUPER-METAL

Metallic hydrogen was theorised to be a superconductor at room temperature in 1968.



© NASA/JPL-Caltech

of the planets are not in the gaseous phase due to the high pressures. Therefore you should think of giant planets as being fluid, and not gaseous."

But these fluids aren't uniform. Below the great oceans of hydrogen, the gas is thought to turn to metal. Under such intense pressures, the electrons of hydrogen atoms are assumed to rip apart from their companion protons. And with these electrons now free to conduct energy, the liquid seas of hydrogen are thought to turn metallic.

This remarkable alchemy has had physicists intrigued for decades. If researchers knew just a little bit more about the transitions between these different states of hydrogen and helium, it could significantly advance their understanding of these gassy titans. "Progress in our understanding of hydrogen and hydrogen-helium at planetary conditions can be used to further constrain structure models of the planets," Helled tells **All About Space**. "The fact that helium can separate from hydrogen, resulting in helium rain in giant planet interiors, is critical to understanding their evolution and internal structures. And the fact that hydrogen metallises explains the strong magnetic fields in these planets."

And planetary scientists aren't the only ones interested in furthering our understanding of metallic hydrogen. Aside from being a fascinating state of matter within the gas giants, the metal is also thought to have multiple practical uses. Thanks to its free electrons, it's theorised that solid metallic hydrogen could be a superconductor at room temperature. If isolated and stabilised on Earth, it would be one of the most efficient materials on the planet for transferring and storing energy. The latter trait could even enable the metal to be used as a highly efficient rocket fuel. Given its potential to launch a whole new era of power, technology and space exploration, there's an understandable interest in learning more about the metal's properties.

Sadly, it's not yet possible to wade through the clouds and seas of Jupiter and collect a beaker of metallic hydrogen for further research. Physicists have had to get a bit more creative. Some have

Above: After orbiting the planet 22 times, the Cassini probe ended its mission and plunged into Saturn on 15 September 2017

tried to recreate the high pressures of Jupiter and Saturn here on Earth in an attempt to engineer their own metallic gases. Just three years ago, two researchers at Harvard University claimed to have succeeded. After squeezing the gas in between two tiny diamonds at a temperature just above absolute zero, the physicists reported in the journal *Science* that their hydrogen sample became shiny and reflective. However, before this sample could be further tested to check if it really was metallic hydrogen, it was lost. And once you lose a microscopic sample of hydrogen, there's apparently not much point attempting to find it...

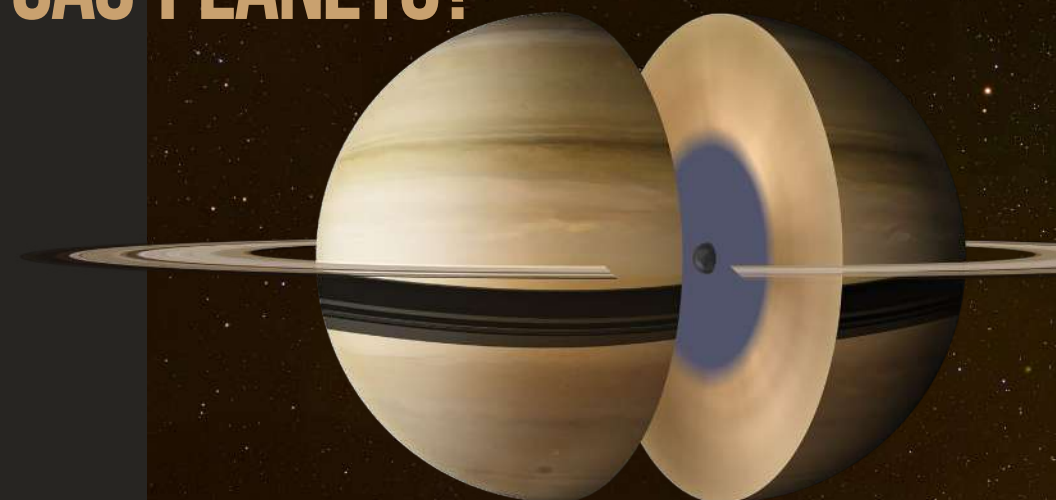
Somewhat expectantly, this experiment and its claims were greeted with a dose of healthy scepticism from the scientific community. "To probe this transition, people have been using various techniques," says Dr Bingqing Cheng, a computational physicist at the University of Cambridge. "For example, you can squeeze the liquid hydrogen between a diamond and then press and see what happens, or there are some

laser-based techniques. But all these studies have a problem: it's very hard to characterise the material under high pressure. We know that this phenomenon transition happens, but experimentally it's very hard to locate."

Are there any more reliable ways of studying metallic hydrogen? Computational physicists like Cheng seem to think so. "The gold standard is always 'seeing is believing'. If something can be done in an experimental lab, that's sort of the ultimate proof," she tells **All About Space**. "But in this situation the experiments are so hard, and it's probably not getting much better in the near future, so theory plays a crucial role there."

The idea put forward by Cheng and her colleagues is that if all the known characteristics of hydrogen could be inputted into a computer, and then that computer ran a simulation of the intense pressures and conditions present within Jupiter and Saturn, scientists may have a much more reliable way of studying metallic hydrogen without ever moving from their laptops. The

WHAT'S INSIDE THE GAS PLANETS?



AMMONIA (NH_3)

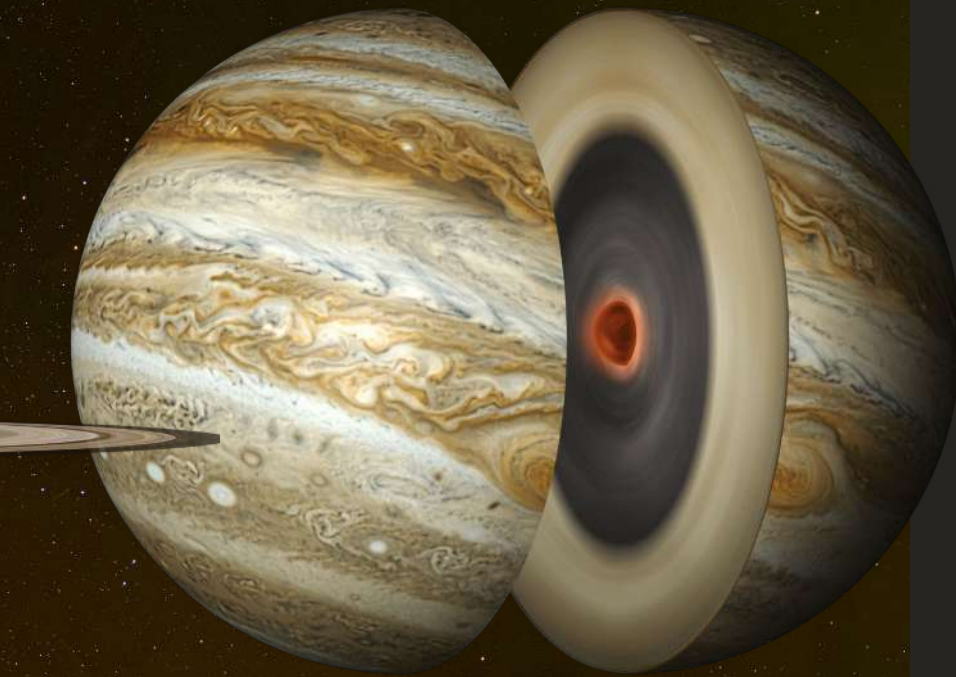
Clouds of ammonia and water are thought to shroud the surfaces of Jupiter and Saturn.

WATER (H_2O)

Recent results from NASA's Juno space probe suggest that these ammonia-water clouds can conduct 'shallow' lightning and rain slushy

HYDROGEN

Together hydrogen and helium account for about 85 per cent of the total mass of Jupiter and 75 per cent of the total mass of Saturn.



HELIUM

Below the planets' surfaces, under temperatures of around 6,500 Kelvin and 1 to 2 million atmospheres of pressure, helium is thought to separate from hydrogen and fall as rain.

HEAVIER ELEMENTS

Recent gravity field measurements from Juno and Cassini indicate that the gas planets have complex, 'fuzzy' cores, which likely contain heavier elements such as iron, nickel and silicon.

MORE ELEMENTS?

As little is currently known about these cores, there may be many more elements and materials contained within them that we are unaware of.

© Tobias Roetsch

only snag is that such simulations would take an ungodly amount of computational power. "Even with the state-of-the-art method we are limited to a few hundred atoms, as well as a picosecond [one trillionth of a second] timescale," says Cheng. "And that is problematic when we are probing a phenomenon such as phase transition, which inevitably requires a large system. The machine-learning potential enabled us to achieve that."

And these machine-learning techniques appear to have done the job. In her research, Cheng and her colleagues announced that they had developed a way of simulating atomic phase changes using artificial intelligence and quantum mechanics. As the machine learning could 'learn' the potential energies and interatomic forces from reference calculations, it could then predict the immediate changes the 1,700 or so atoms would undergo when submitted to a broad range of temperatures and pressures. Without having to wait millions of years for a result to compute, Cheng's team managed to map the entire phase diagram of dense hydrogen. After processing the data, they found metallic hydrogen undergoes a continuous transition from molecular to atomic states in the liquid phase, with no first order transition observed above the melting line. In other words, the fluid-to-fluid transition is, in fact, fluid.

While this nebulous boundary between the molecular-hydrogen and metallic-hydrogen layers of gas planets had been guessed at by some physicists prior to Cheng's study, her team's

results have helped confirm, theoretically at least, that the tiers of Jupiter and Saturn

JUNO AT WORK

1 Microwave radiometer (MWR)

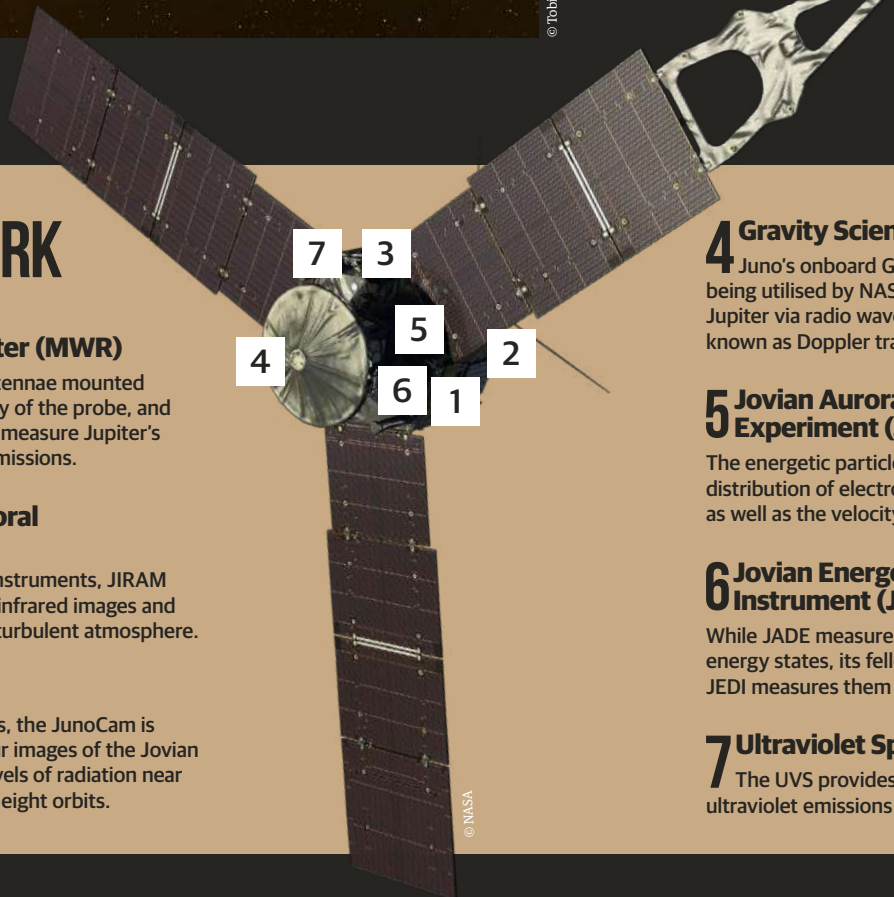
The MWR comprises six antennae mounted on two of the sides of the body of the probe, and is used by Juno's operators to measure Jupiter's atmospheric circulation and emissions.

2 Jovian Infrared Auroral Mapper (JIRAM)

One of Juno's most versatile instruments, JIRAM has been designed to acquire infrared images and study the spectra of Jupiter's turbulent atmosphere.

3 JunoCam (JCM)

One of Juno's main imagers, the JunoCam is capable of taking visible-colour images of the Jovian cloud tops. Due to the high levels of radiation near Jupiter, it's only set to survive eight orbits.



© NASA

4 Gravity Science (GS)

Juno's onboard Gravity Science equipment is being utilised by NASA to test the composition of Jupiter via radio waves. It does this via a process known as Doppler tracking.

5 Jovian Auroral Distributions Experiment (JADE)

The energetic particle detector, JADE, measures the distribution of electrons in the Jovian atmosphere, as well as the velocity and composition of ions.

6 Jovian Energetic Particle Detector Instrument (JEDI)

While JADE measures ions and electrons at low energy states, its fellow energetic particle detector JEDI measures them at high energies.

7 Ultraviolet Spectrograph (UVS)

The UVS provides Juno with the ability to detect ultraviolet emissions from the atmosphere.

Jupiter and Saturn

are not finite. Unlike the rigid crust, mantle and core classifications of Earth's interior, the inner structures of the gas giants stay true to their hazy nature.

"A previous assumption was that the transition is sharp," Cheng says. "To make an analogy: when boiling water, you see the temperature starts to increase, and then all of a sudden you start to have vapour. It's a very sharp transition. But it's also easy to imagine that when this happens, the volume of the density changes suddenly. But actually, if you boil water at very high pressure in the super-critical region, this transition would happen smoothly.

"Our simulation basically suggests that hydrogen-hydrogen actually sits in that super-critical region," she explains. "Take Jupiter, for example. If you dive into [it] from the surface, which has a low pressure, to the centre, you wouldn't see an abrupt change."

Unfortunately, there's currently no way to verify Cheng's results with an actual voyage into Jupiter's interior. But the few probes that have raked the surfaces of Jupiter and Saturn for data have made some key corroborating discoveries. Thanks to measurements taken by the Juno spacecraft, launched by NASA in 2011, astrophysicists now have further evidence that Jupiter's core has a fuzzy boundary, as its heavier elements appear to peel off for up to half its radius.

"Recent formation models and the available gravity field measurements of the planets from the Juno and Cassini missions indicate that the planets have complex interiors which include composition gradients and fuzzy cores," Helled tells **All About Space**. "Fuzzy-dilute cores can extend to a few tens of percents of the planet's total radius, and could also consist of lighter elements, such as helium and hydrogen."

On the surface of things, the existence of these fuzzy cores only further muddies the composition of the gas planets. But when combined with the results of Cheng's simulations, the picture of these giants actually becomes a lot clearer. Starting from a fuzzy core of known and unknown materials, the planets appear to bleed out their elements into their surrounding layers. These coats of metallic hydrogen, helium rain and molecular liquid hydrogen, each thousands of kilometres thick, are now thought to diffuse into each other, with no fixed boundaries. And all of these tiers, both distinct and hazy, are eventually capped off with a relatively thin covering of gaseous clouds of ammonia, methane and ice.

It's now more evident than ever just how otherworldly these other worlds are. "Juno really revolutionised our understanding of Jupiter," says Helled. "The mission is still ongoing, and we are looking forward to the new data. The Cassini mission revealed comparable information

Below: Jupiter, as captured by NASA's Juno probe during its eighth orbit



Leo Bear-McGuinness
Space science writer

Leo holds a master's degree in science communication. He has written about space and science for a variety of magazines and websites.

HOW SPOOKY SCIENCE HELPS US PEER INSIDE THE PLANETS



MICHELE CERIOTTI

An assistant professor of computational science at the EPFL research centre in Lausanne, Switzerland, involved in the current research on metallic hydrogen.

Could you explain how the machine-learning techniques used in your research work? Why were they preferable to standard computational methods?

The idea is very simple - this is basically using a very flexible functional form to interpolate the predictions of the energy and forces acting on atoms, as obtained by solving the Schrödinger equation.

This basically gives you the same accuracy as the horribly complex - and computationally demanding - electronic structure calculations at a tiny fraction of the cost. This allows us to simulate larger systems for longer times, getting us closer to the behaviour you would expect from a macroscopic sample.

How reliable are the results produced from such techniques? Could they be verified by other researchers, for example?

These are definitely reproducible; we share all of the data that is needed to replicate our simulations. Errors may arise from two sources. One is the interpolation procedure. This we could test extremely carefully, so we are convinced we obtained the same accuracy as the explicit quantum calculations. The other are the quantum calculations themselves, that are also necessarily an approximation. This can't really be tested explicitly, but we compared three different kinds of approximations of the Schrödinger equations and obtained qualitatively equivalent observations, which is a strong indication the findings are robust.

Which part of the research are you particularly proud of?

What I like about this work is that it is the result of five years of effort in my group to combine machine-learning potentials with advanced statistical sampling techniques. I think often the technical effort that goes towards developing algorithms and methods is harder to receive the same level of recognition, so it is very satisfactory when you can show that all the hard work enables us to achieve scientific findings of great relevance.

about Saturn. This is fantastic since we can now compare the two giant planets in our Solar System. While many questions remain open, this is a true golden era in giant planet exploration. The measurements of the ongoing Juno mission, the characterisation of many giant planets around other stars and the efforts in high-pressure physics provide new insights on the nature of hydrogen-helium-dominated planets."



© NASA/JPL-Caltech

DARK MATTER GALAXY DEBUNKED

Astronomers claimed a galaxy was 98 per cent dark matter... but they were wrong

Back in 2016, researchers claimed to have found a galaxy made almost completely of dark matter. Now that claim has fallen apart. The galaxy, Dragonfly 44 (DF44), belongs to a class of mysterious objects known as ultra-diffuse galaxies, or UDGs. Researchers have debated since the 1980s whether these vast, dim objects have a low mass, like dwarf galaxies smeared across huge reaches of space, or are heavy, Milky Way-style galaxies that seem dim for two reasons: because they have almost no stars, and because a huge fraction of their mass is dark matter found in the outer fringes of the galaxy in so-called dark matter haloes that emit no light. In a paper published in 2016 in *the Astrophysical Journal Letters*, scientists argued that DF44 was one of these galaxies with a big dark matter halo and few stars. They estimated its mass and found it was at least 98 per cent dark matter.

But a new analysis suggests the earlier study got it wrong. Researchers in the 2016 study assumed a bunch of mass was globbed into the dark matter halo, but the new study showed a much lower total mass, indicating DF44 is one of those low-mass dwarf galaxies spread across space with normal percentages of dark matter. DF44 is about 360 million light years from Earth, so astronomers can't directly

measure its mass. Instead they rely on proxies. Features like the speed at which objects circle a galaxy can indicate how massive it really is, as more gravity would cause objects to whirl faster.

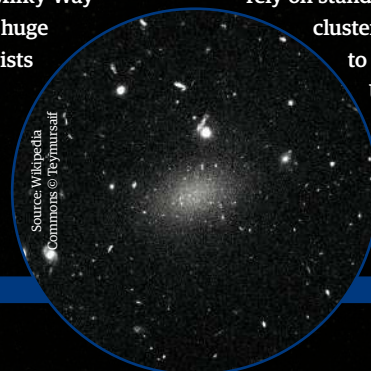
In 2016, researchers claimed DF44 had a huge halo because of how fast its globular clusters seemed to whirl around its centre. Those velocity measurements turned out to be incorrect. But that wasn't the end of the argument that DF44 had a huge amount of dark matter. That's because the galaxy did seem to host a relatively high number of globular clusters.

Researchers have found a general relationship between the number of globular clusters in a galaxy and that galaxy's mass, said the study's lead author Teymoor Saifollahi, a doctoral candidate at the University of Groningen in the Netherlands. And DF44 did seem to have more globular clusters than you'd expect for a galaxy with so few stars. Early observations estimated about 100 of these clusters, which was later narrowed down to 80 in a 2017 paper. That puts the mass of DF44 squarely in Milky Way territory - a jarring result with huge implications for how cosmologists understand the history of galaxy formation. In the new model, galaxies would be primarily dark matter

objects, able to form without many stars or other luminous matter at all.

Saifollahi and his colleagues did their own count, though, landing on a much lower number: 20. That would indicate that DF44 has a normal dwarf galaxy mass - a much less exciting result. The key difference between the 2017 analysis and the 2020 analysis, Saifollahi said, has to do with where they assumed most globular clusters in DF44 were located. The 2017 team made a rough guess as to how far the clusters would orbit from the centre of the galaxy, based on standard numbers associated with dwarf galaxies, and then looked for candidates in that area. For the 2020 paper the researchers actually measured how far the clusters extended from the centre of the galaxy, and found that the stellar globs clustered much closer to DF44's centre than expected. Counting possible clusters only in that smaller area produced a smaller number.

In future studies of UDGs, Saifollahi said, scientists will have to be more careful not to rely on standard assumptions about globular clusters. He and his colleagues plan to more closely examine other UDGs that have high estimated numbers of globular clusters and see if those estimates hold up.



Source: Wikipedia Commons © Teymoor Saifollahi

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MYSTERIES
OF THE
UNIVERSE

WHAT LIES BETWEEN NEUTRON STARS AND BLACK HOLES?

There has long been thought to be a mass gap between these two cosmic heavyweights, but does the theory need to be revised?

Reported by David Crookes

Scientists know about neutron stars. They're very much aware of black holes, too. But what if there's something in between? This is what astronomers are pondering having discovered a cosmic event called GW190814. It was found through the detection of gravitational waves on 14 August 2019, and involved an object of a mass that had never been seen before.

Up to that point, the heaviest known neutron star was found to have a solar mass of 2.3, with the lightest known black hole being about five solar masses. Yet GW190814 pointed to an object of 2.6 solar masses, making it either the heaviest neutron star ever seen, the lightest black hole or perhaps even something else entirely. It's so significant that it's set to change how we look at neutron stars

and black holes, not least because it poses a great challenge to current theoretical models.

For years astronomers have worked on the assumption of a 'mass gap' to explain why there are no objects with a solar mass greater than 2.3 or less than five. But now that an object involved in the GW190814 event sits firmly within the gap, albeit at the lower end, that assumption must be revised. "The mass spectrum is not thought to be continuous – there are gaps in it," explains Dr Laura Nuttall, senior lecturer in gravitational waves at the University of Portsmouth's Institute of Cosmology and Gravitation.

"At the lower end we have black holes with masses about the same size as the Sun – they're called solar mass black holes. At the higher end we find black holes with masses that are millions

THE MASS GAPS BY THE NUMBERS

2.6

Size in solar masses of the discovered object

23

Size in solar masses of the black hole

3,000

Number of kilometres between the two detectors making up LIGO

2019

Year the object was discovered, on 14 August

20

Diameter of a neutron star's core in kilometres

8 BILLION

tonnes in a single teaspoon of neutron star matter

800,000,000

light years to the object's location from Earth

6X

farther away than a merger discovered in 2017

25

Size in solar masses of the final black hole produced by the merging of the two objects

OBSERVING COLLISION EVENTS

LIGO-Virgo has been key to the discovery of many mergers through the detection of gravitational waves

1 Discovering neutron stars

The objects in yellow were measured through electromagnetic observations. They are the size of neutron stars.

2 Spotted by LIGO-Virgo

These neutron stars were discovered by LIGO-Virgo. They are the corresponding measurements of the yellow depictions using gravitational waves, and they are seen to merge to form new objects.

5 Creating a black hole

The merger produced another black hole. The mystery object was discovered to be nine-times less massive than the black hole it merged with.

4 The mystery merger

Scientists were able to detect the event GW190814. This involved the merger of a black hole with this mystery object, measuring 2.6 solar masses.

3 Observing black holes

The objects in purple are black holes, as measured through electromagnetic observations. You can see that they are of a greater solar mass than the neutron stars.

Left: An artist's impression of two black holes - one nine-times more massive than the other - spiralling into each other and colliding

of times that of the Sun, called supermassive black holes. When people talk of the mass gap, they may be referring to the realm between neutron stars and black holes. For a while we haven't known if this gap is real, or whether there is a continuous spectrum and our instruments haven't been able to see any yet." Little wonder the object involved in GW190814 is being seen as a game changer. Maybe there is no mass gap after all.

Before we look more deeply into this mystery, however, it's worth refreshing our minds about the difference between neutron stars and supermassive black holes. Both are formed when a massive star dies and explodes, resulting in the small, dense core that's left behind gradually collapsing under its own gravity. As it does so, protons and electrons are

crushed together into a neutron, and if the core is less than three solar masses, a dense, dead remnant - the neutron star - will remain.

If the mass is great enough, however, the collapse will become more severe, and this will lead to a black hole. But why do lighter cores form neutron stars and those from heavier ones form black holes? Nuttall, whose gravitational-wave group played a key role in the study along with other universities across the world, explains: "It's all to do with mass. When a massive star collapses, we usually think that either a neutron star or black hole forms, but you might be better thinking that they will all form a neutron star first.

"If more mass is then added to the neutron star because of the collapse of the star, there will be a limit at which the neutron star can be stable. This is to do with 'neutron degeneracy' - the pressure which the neutron star fights against gravity - and it's down to quantum physics. "Here no neutrons can exist in the same quantum state, but if you try to add more and more mass to this object, at some point the neutron star will become unstable and collapse further into a black hole."

When neutron stars and black holes merge or collide, it results in gravitational waves. And over

"FOR A WHILE WE HAVEN'T KNOWN IF THIS GAP IS REAL, OR WHETHER THERE IS A CONTINUOUS SPECTRUM"

LAURA NUTTALL

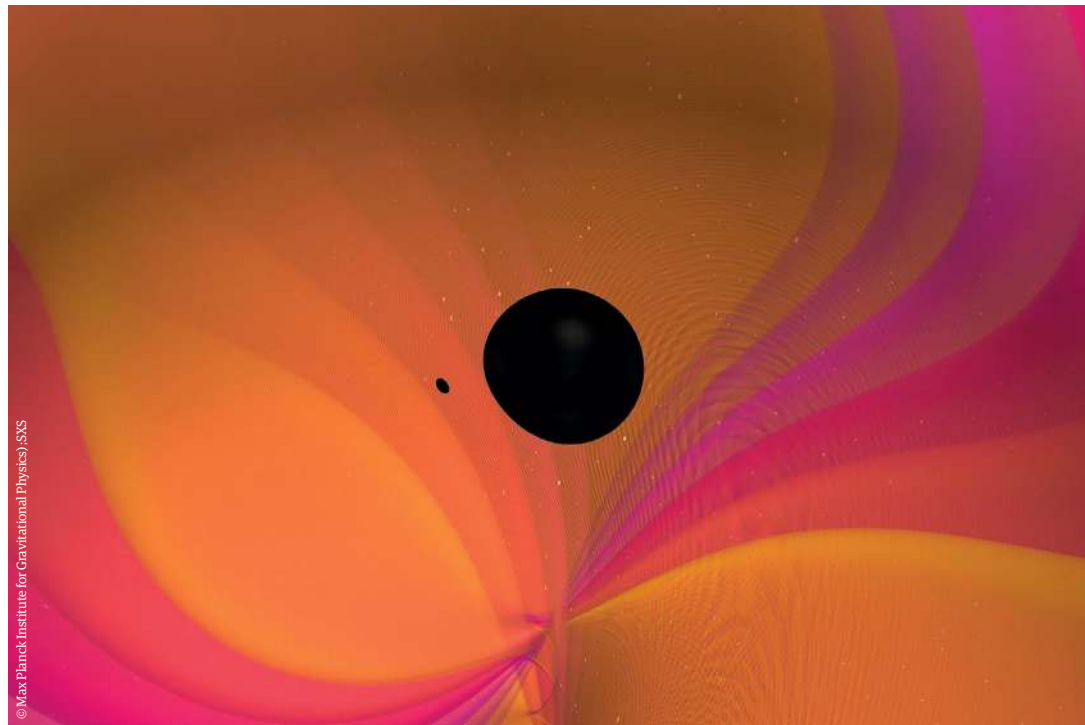
the past five years these have been detected. Indeed, in 2017 and 2019, observations were taken of two sets of colliding neutron stars, with the resulting ripples in space-time - predicted by Albert Einstein 99 years earlier - being picked up by the National Science Foundation's Laser Interferometer Gravitational-Wave Observatory (LIGO).

Space-time ripples have also been observed from merging black holes, and such discoveries have been a huge justification for creating LIGO. It began collecting data in 2002 from its two detectors: one in Livingston, Louisiana, and the other in Hanford, Washington. They are 3,000 kilometres (1,864 miles) apart, and in the case of GW190814 were used in combination with the Virgo detector in Italy. But what actually happened during GW190814? There was a merger of an object with a black hole containing 23 solar masses of material, and it was discovered that prior to this merger the other object's mass differed by a factor of nine, making it the most extreme mass ratio for a gravitational-wave event yet. It resulted in a final black hole 25 times the mass of the Sun, with some of the mass converted to gravitational waves. Scientists say it is about 800 million light years away from Earth, but they're not entirely sure how to identify the object involved in the merger with the black hole.

"The mystery object may be a neutron star merging with a black hole, an exciting possibility expected theoretically but not yet confirmed observationally," says Professor Vicky Kalogera from Northwestern University in Evanston, Illinois. "However, at 2.6 times the mass of our Sun, it exceeds modern predictions for the maximum mass of neutron stars, and may instead be the lightest black hole ever detected."

Nuttall is erring towards the mystery object being the latter. "Right now it's looking like a light black hole - or at least the simplest explanation is a really light black hole," explains Nuttall. Even then, though, there are many more questions, not least if light black holes can indeed exist. Remember, this one would be just 2.6 solar masses compared the previously lightest black hole of no less than five solar masses. If this is the case, then how are they forming? "Are they being produced from the mergers of neutron stars or from stars collapsing?" Nuttall says of the conundrum. And the answer? "The jury is still out."

For how long is anyone's guess. Since the merger was discovered the astronomical community has been in full swing, using ground- and space-based telescopes to search for any light waves that would have been generated. It's no easy task, especially given that light waves resulting from a gravitational wave event have only ever been spotted once before, back in August 2017 when two neutron stars



Above: A visualisation of the coalescence of two black holes merging and emitting gravitational waves - one nine-times more massive than the other

Below: Kalogera compares the merger involved in GW190814 to "Pac-Man eating a little dot"



THE THEORIES

What could the mystery object discovered in the mass gap actually be?

Heaviest neutron star

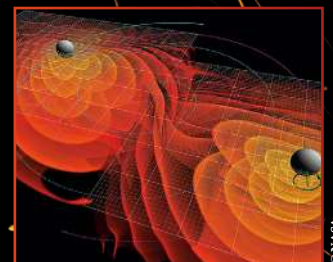
Since the object's measurements place it at the lower end of the mass gap, it is closer in size to neutron stars than black holes. However, at 2.6 solar masses, it exceeds the limit for a neutron star's maximum mass. This was thought to be 2.3, but astrophysicists at Goethe University Frankfurt set it as low as 2.16 in 2018. Most neutron stars have a mass of 1.4 solar masses.



© NASA

Lightest black hole

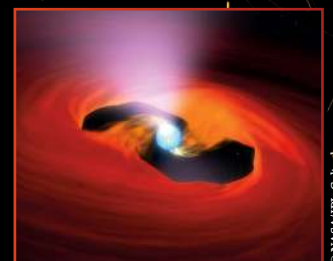
The most favoured explanation is a black hole, because no light was detected during the event of August 2019. This theory works because two merging black holes would not produce any light. But this could also be due to the object being too far away. A neutron star with nine-times less mass than the black hole would also be gobbled up in one, again producing no light.



© NASA

Rapidly spinning neutron star

Maya Fishbach, a member of the LIGO Scientific Collaboration, says we can't dismiss this theory. "Mainly because I think that would be really cool," she tells us. A rapidly spinning neutron star would be able to support more mass: the maximum of 2.3 solar masses refers to a non-spinning case. "It would have to be spinning pretty quickly, though," she adds.



© NASA/JPL-Caltech

spiralled closer to each other, collided and finally merged. The gravitational-wave signal lasted 100 seconds, but 11 hours later a fast-moving, rapidly cooling cloud of neutron-rich material ended up being observed by dozens of telescopes. This event, GW170817, was considered to be the biggest breakthrough of the year.

The difference between GW170817 and GW190814, however, is that a collision between two neutron stars is expected to give off light. When an object merges with a black hole, though, the situation isn't quite as straightforward - black hole mergers are not thought to produce light. Given those circumstances, it's perhaps no surprise to learn that optical or infrared radiation hasn't been detected. Does this entirely rule out a neutron star?

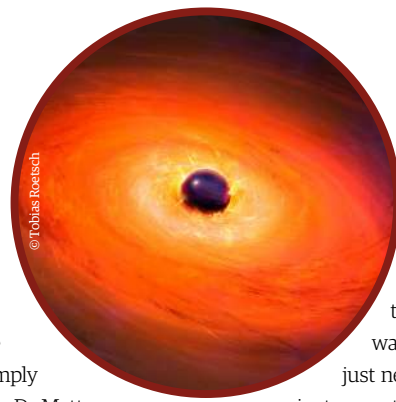
No, but in truth the evidence stacks against it being one. Astrophysicists work on the assumption that there should be an absolute upper limit for the mass of a cold, self-gravitating body, and this manifests itself as the Tolman-Oppenheimer-Volkoff limit. It's the point at which the core of a neutron star becomes so massive that neutron pressure is overwhelmed by gravity, leading the object to collapse into a black hole. That limit is calculated to be no more than 2.4 solar masses.

Is this why light isn't being emitted? Not necessarily. The black hole in GW190814 was nine-

times larger than the other object, which means whatever collided with it is likely to have been gobbled up in a cosmic instant, preventing any light from shining. "Its more massive black hole partner may have simply swallowed it up whole," explains Dr Matt Nicholl, a lecturer at the Institute for Gravitational Wave Astronomy at Birmingham University.

GW170817 was also six-times closer to Earth, which made it easier to pick up on any light. But it does look more likely to be a small black hole, and all researchers can do is look out for similar collisions pointing to objects within the mass gap. Is that possible? Surely the evidence is now suggesting that the object involved in GW190814 isn't the only one, but there must still be a reason why we're just not seeing them. "In terms of gravitational waves, there could be a few reasons," affirms Nuttall. "First, it seems quite hard to make a system like GW190814: it has a high mass ratio - a small object with a larger object - and it's typically thought that these objects form in dense gravitational environments like globular clusters.

"But they do seem to be more common than previously thought, since we've detected one system. Now if we think about systems with



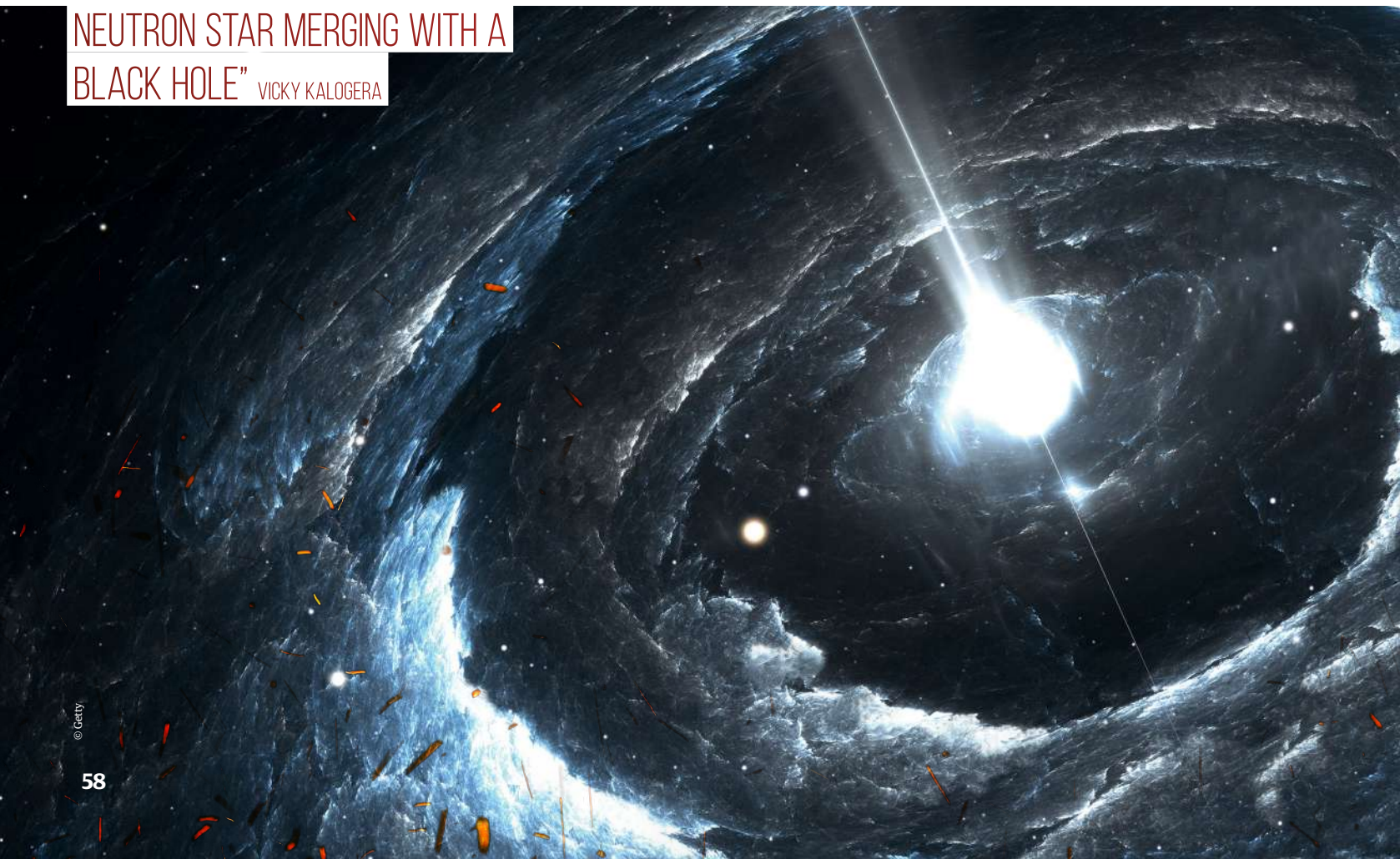
similar masses, then smaller mass systems will need to be closer for us to detect. The heavier objects are, the larger the amount of gravitational waves that are given off. "We may just need to wait for more sensitive instruments. On the electromagnetic side of things I think this is also the case. There could be a selection effect going on."

One thing's for sure: odd instrumental behaviour has been largely ruled out. The object in the GW190814 event really does appear to be 2.6 solar masses. It's also the only one scientists have ever observed to be within the mass gap, even though GW170817 was found to have created an object of 2.8 solar masses when the neutron stars collided.

"We're not sure from the gravitational wave side what this remnant was because the data isn't good enough. In the future we hope that our detectors will become sensitive enough to measure a post-merger signal," says Nuttall. "But astronomers have looked at X-ray data from GW170817, and I think the consensus currently is that a long-lived neutron star was created and then collapsed into a black hole."

Astronomers are learning a lot about the dynamics of stars, and they are at the beginning of discovering what gravitational waves can tell

"THE MYSTERY OBJECT MAY BE A NEUTRON STAR MERGING WITH A BLACK HOLE" VICKY KALOGERA



them about the mass gap. With LIGO, many more breakthroughs are expected, and scientists are excited by the possibilities. "In only five years we have observed 13 black hole mergers and two neutron star collisions, and we have yet to tell the world everything about the third observing run, which concluded in March 2020.

"We are starting to understand more about black holes and neutron stars, and how this feeds back to how stars live and die. We know black holes that are tens of times the mass of the Sun exist. We know that right now everything follows general relativity, and that neutron star collisions produce short gamma-ray bursts and are a site for the production of heavy elements.

"We're now starting to detect objects in this mass gap, and they look like black holes. Over the next few years the LIGO, Virgo and the Kamioka Gravitational Wave Detector in Tokyo are going through upgrades to increase sensitivity, and will start listening to the universe again in 2022. What else are we going to find?"



David Crookes

Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

Left: A small black hole could have formed from a previous neutron star merger event

Below: Black holes tend to be about five times the mass of the Sun, so a black hole at 2.6 solar masses is certainly intriguing

WHAT GAPS IN OUR KNOWLEDGE REMAIN?

Maya Fishbach is a postdoctoral fellow at Northwestern University and a member of the LIGO Scientific Collaboration



Could there still be a mass gap?

We still need more observations of compact objects before we can definitely conclude whether or not there is a mass gap - and where it is located. This is exactly what I'm trying to figure out with more gravitational-wave data from LIGO and Virgo. My collaborators and I analysed the first 11 observations from LIGO and Virgo, which included ten binary black holes - with masses bigger than around seven solar masses - and one binary neutron star - with masses smaller than two solar masses. However, this was before GW190814, with the 2.6 solar mass object.

What is the evidence showing?

We found that based on those 11 data points, which included objects on both sides of the gap - but nothing in the gap - there was preliminary evidence for a mass gap. In other words, if there wasn't a mass gap, we would have expected to already have detected something in the two to seven solar mass range in the first two observing runs, and we didn't. GW190814 definitely complicates this picture, but many options are still possible. There could be a mass gap between 2.7 solar masses and five solar masses, for example, instead of 2.2 solar masses to five solar masses. Or there might be a 'dip' in the mass distribution instead of a totally empty gap.

On 17 August 2017, a signal was detected which appeared to suggest the discovery of an object of 2.8 solar masses. Is this in the mass gap?

The 2.8 solar mass object detected in 2017 was the result of a collision between two 1.4 solar mass neutron stars. We don't know the fate of the final object from the gravitational wave signal, but there is evidence that the final object was a black hole. So yes, this object is definitely in the mass gap. However, there is a key difference: the 2.8 solar mass object was formed from a merger of two neutron stars, not from a star undergoing a supernova explosion and collapsing into a neutron star or black hole. On the other hand, we think that the 2.6 solar mass object in GW190814 was formed directly from stellar collapse.

Why do scientists think that this was the case?

We don't expect that the merger product of two neutron stars could ever find another neutron star or black hole to merge with - although if this was how the 2.6 solar mass object formed, it would also be an exciting result. Prior to this observation people thought that when stars undergo supernova explosions and collapse to a neutron star or black hole, something about the supernova mechanism would create a gap between the neutron star and black hole masses.



© LIGO

SOLAR SYSTEM

Why don't Mercury or Venus have any moons?

Planets have a region around them where orbiting objects can be gravitationally bound. In planetary science this is called the 'Hill sphere', named after 19th-century American astronomer George Hill, who worked on the Moon's orbit. The size of the Hill sphere depends on how massive a planet is in comparison to the Sun, and how close it is to the Sun.

Any bound object must orbit inside the Hill sphere. But for its orbit to be 'stable' it needs to orbit at less than about one-third of the radius of the Hill sphere. Therefore we expect that all moons must orbit at less than about a third of a Hill sphere radius.

There are other restrictions on where we expect to find moons. Earth's Moon interacts tidally with Earth - it raises tides on Earth, and that gradually changes the Moon's orbit. Because the Earth spins faster than the Moon orbits - the day is shorter than the month - the effect of this interaction is to move the Moon away from us at a rate of about four centimetres (1.5 inches) a

year. A moon in orbit around Mercury or Venus - which spin slowly - would evolve in the opposite direction, with its orbit gradually shrinking. This happens at Mars, where Phobos orbits rapidly with a shrinking orbit, and Deimos orbits slowly and much farther away, with an orbit that is growing with time.

So how big are Hill spheres? Venus and Earth are almost twins: similar mass, similar distance from the Sun. The Hill radius of Earth is about 230 Earth radii, for Venus about 166 Venus radii and for Mercury about 72 Mercury radii. For Mercury it's pretty clear that there isn't much room for a moon in the stable region, and if there were it would rapidly fall into the planet due to

tidal interactions - the speed with which tides can move moons increases sharply as the moon gets close to the planet.

There is a little bit less room for a moon at Venus. Not much less, so the real mystery is why Venus doesn't have a moon. There are lots of ideas about this. One possibility is that Venus did have a moon and it later collided with the planet. We think Earth's Moon formed in a giant collision between a Mars-sized body and the proto-Earth, which was something of a random event - maybe Venus escaped such a giant impact by luck, whether good or bad.



Charles F. Gammie is a professor of physics at the University of Illinois

"FOR MERCURY IT'S PRETTY CLEAR THAT THERE ISN'T MUCH ROOM FOR A MOON IN THE STABLE REGION" CHARLES F. GAMMIE

Below:
Although some planets have dozens of moons, Mercury and Venus have none

SPACE EXPLORATION

Does space have a smell?

I am the creator of the fragrance Eau de Space, and I was originally approached by someone working at NASA back in 2008 with an idea to help make astronaut training more realistic by creating the smell experienced after walking in space. I don't believe it was ever used in this way, but although I didn't get to go into space myself or get to smell any spacesuits, I did receive transcripts of interviews with those astronauts that had walked in space. These included descriptions of what they experienced as an unusual odour when they returned to the safety of the capsule or Space Shuttle cabin.

The astronauts' descriptions were consistent: hot metal, fried steak, burnt meat - almost a barbecue. One even mentioned it being reminiscent of welding on his motorbike. It is possible that there may have been some organic materials around, but I am not convinced anything like the complex pyrazines that would create the meaty smell are likely to exist in space.

I think this is more likely high-energy particles and resulting ionisation impinging on the sensory epithelium once exposed back in the

space capsule. Of course it is only apparent when re-entering the capsule through the airlock and removing their helmets. The astronauts then describe their sensory experience in the best terms and using descriptors that make sense to them. Interestingly, however, other crew, not having walked outside, also reported similar sensations as their crewmates returned and brought this odour in with them.

I was able to use my experience and knowledge of flavour, fragrance and aroma chemistry to work with the descriptions from the astronauts and chose the most appropriate materials. As with all this type of creative development, it is then about finding the most appropriate levels of materials to work together to produce the final perceived fragrance.

Steve Pearce is CEO of Omega Ingredients, which created



and manufactured the smell of space: Eau De Space

Below: Could you bottle the scent of space? Omega Ingredients has



Did you know?

Estimates suggest there are between 100 and 200 billion galaxies in the universe.

Above: In 1999 astronomers discovered a spiral galaxy which may rotate in the opposite direction than expected

© NASA and the Hubble Heritage Team

ASTROPHYSICS

Why don't we see galaxies rotating?

Humans do not notice the rotational motion of galaxies because galaxies are so unimaginably large. Galaxies are so large it takes them a long time to complete one rotation. For instance, our galaxy takes about 240 million years to complete one full rotation at the location of our Sun.

The rotation rate of a galaxy is extremely slow. Even though the stars in our galaxy are travelling at about 500,000 miles [804,672 kilometres] per hour relative to the centre of our galaxy, the galaxy is so large that it still takes hundreds of millions of years to complete a lap.

Humans have eyes and brains that are built to notice motion involving changes in position and orientation that happen on the scales of milliseconds to hours, not years, and definitely not millions of years. Galaxies rotate too slowly for humans to notice their motion.



Christopher S. Baird is assistant professor of physics at West Texas A&M University



SOLAR SYSTEM

What would life be like on Earth if we orbited a white dwarf?

White dwarfs are stars that have reached the end of their lives. They have masses similar to our Sun, but that mass is contained in an area about the size of Earth. These stars no longer have fusion going on in their cores. They cool over time, so the environment on an orbiting planet would go from warm to cold in general.

The 'habitable zone' is at a distance of 0.005 to 0.02 AU - this is 200 to 20-times closer to the star than Mercury is to our Sun. While there could be a habitable zone, planets this close to a star are likely to be tidally locked. This means that seasons and days on such a planet would be very different than we have on Earth.

If a planet was synchronously tidally locked, life on one side of the planet would know they were orbiting a star, while life on the other side would never actually see the star they are orbiting. Temperatures on one side of the planet would be much warmer than the other side unless there was a significant atmosphere. If there was a way to get an Earth-like planet into orbit around a white dwarf star, the environment would likely be very extreme, and life would be very different than we experience on Earth.

Susan Benecchi is a senior scientist at the Planetary Science Institute



Left: Climate would certainly change if Earth orbited a white dwarf like this Neptune-like exoplanet around the white dwarf WD J0914 +1914

Right: Wormholes are speculative structures which are said to link disparate points in space-time

Below: Is anyone out there? SETI hopes the Allen Telescope Array will pick up signs of alien life



COSMOLOGY

If we could look through a wormhole, what would we see?

Seeing something means light from the object travels to your eyes, so if you look through a traversable wormhole, you would see the objects on the other side, with the light rays from them coming to your eyes through the wormhole. This would typically lead to some distortion of the image, how extreme depending on the size and curvature of the wormhole, as well as other details.

Traversable wormholes require the local energy density to be negative in some region - this is because gravity is attractive and will always cause ingoing paths to bend inward, which will make it impossible for them to escape the interior. You need negative energy to allow escape from the other side of the wormhole. Isolated negative energy seems incompatible with the laws of physics, but it's known that quantum effects can result in some localised negative energy. To get a traversable wormhole, the total gravitational effect inside the wormhole has to be of the 'outbending' type, and it was believed that this was impossible to arrange, related to something called the average null energy condition.

HUNT FOR LIFE

Is it likely that intelligent alien life could communicate with or understand us?

Conversation is impractical unless we're very close. To understand why, imagine that the Milky Way is stuffed with a million alien societies. The nearest to us will be about 100 light years away. If we detect a signal from these cosmic neighbours and grab a microphone to ask a penetrating question, it will take at least 200 years before we can expect an answer - so don't count on conversation.

But would we be able to understand the signal we picked up? That would be interesting in the same way that reading texts penned 2,000 years



We found a loophole if there's a direct connection between the two ends of the wormhole through ordinary space. That means that signals can only get through the wormhole if a signal can be sent directly. A non-traversable wormhole - so a pair of black holes with spatially joined interiors, but one which nothing can get through - is equivalent to a pair of quantum-entangled black holes. The wormhole is the physical, geometric realisation of entanglement. Our set-up, where a direct signal is sent between the two sides that renders the wormhole traversable, is equivalent to quantum teleportation: the astronaut sent through the interior of the entangled black holes is like the qubit sent in quantum teleportation, and the direct signal is the measurement protocol required to do quantum teleportation.



Daniel L. Jafferis is professor of physics at Harvard University

ago by Julius Caesar is still interesting, even though we can't have a conversation with him.

If the aliens want us to understand, they might make the task simple, just as the writers of children's books do. Some people have suggested that the extraterrestrials could make their message simple for us by using music or mathematics, as these are things that we both might know about. But frankly, it's not easy to communicate with math or melody. How would you describe your family, for instance?

Probably a better strategy is to just send us a lot of information. That would allow us to emulate researchers who have tried to decode Maya script or even Egyptian hieroglyphics. They look for redundancy in the text - for repeating characters - and work from there. With a really long message, there will be plenty of repetition. If we want to understand what the aliens are saying, we better hope that they send us gigabytes of data.



Dr Seth Shostak, senior astronomer at the SETI Institute

COSMOLOGY

Could a mirror universe exist?

Some physicists have been led to consider this possibility by certain puzzling features of the fundamental laws of nature and the observed properties of the universe just after the Big Bang.

In one variant of the idea, the laws of nature in the mirror universe are a reflected version of our own laws. In our universe, left-handed particles - like the neutrino - feel the weak force, while right-handed particles do not; but in the mirror universe, the opposite is true. In this variant, our universe and its partner might lie 'next to each other', like the two sides of a piece of toast, but might be separated from one another by a fourth dimension of space - represented by the thickness of the toast in this analogy - which is much harder to move in than the ordinary three dimensions with which we're familiar in day-to-day life.

In another variant, called the 'CPT-Symmetric Universe' scenario, our universe and its mirror universe are related by CPT symmetry, which is a fundamental symmetry of nature where we take any system and simultaneously reflect it in a mirror, run it backwards in time and swap every particle with its antiparticle. Our universe and its mirror universe may then be visualised as two cones which are joined tip-to-tip, and the point where they touch is the Big Bang. In this variant the mirror universe is separated from us by the Big Bang, and in a sense lies before the Big Bang from our perspective.

At the moment these mirror universe ideas are just intriguing speculations, not solid facts. Future experiments, especially involving neutrinos, will provide further evidence for or against them.

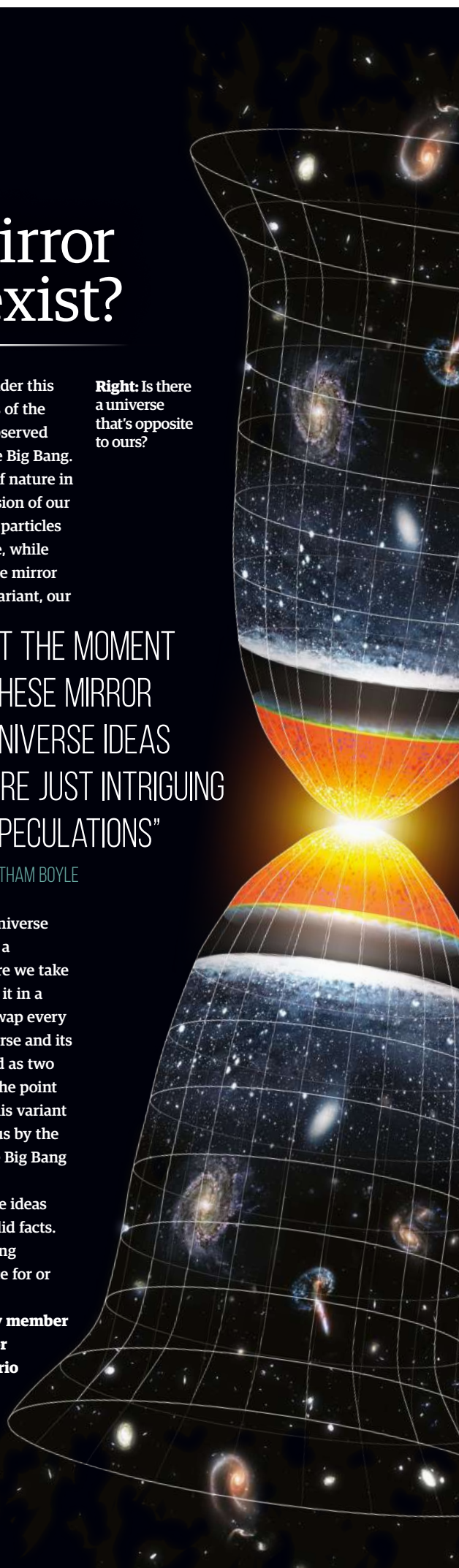


Dr Latham Boyle is a faculty member at the Perimeter Institute for Theoretical Physics in Ontario

Right: Is there a universe that's opposite to ours?

"AT THE MOMENT THESE MIRROR UNIVERSE IDEAS ARE JUST INTRIGUING SPECULATIONS"

LATHAM BOYLE



SPACE EXPLORATION

What causes microgravity

Microgravity is a condition which makes people or objects appear weightless. Astronauts experience weightlessness not because gravity goes away, but because they roll with it.

The International Space Station is not far away: 250 miles [400 kilometres] up. At that altitude the pull of Earth's gravity is still 88 per cent as strong. With nearly as much gravity as us, the space station is constantly falling. It would hit the ground in about five minutes. The station is zooming sideways at five miles [eight kilometres] per second. By the time it would have crashed, the station zoomed over the horizon, and the curvature of Earth moved down the goal posts. Everything inside falls at the same speed, including the astronauts. So although they are still falling, they don't notice because the floor is falling too.

We usually sense gravity as the floor pushing up through our legs or seat. It is so familiar that we only notice when it disappears - on a roller coaster, or when a lift descends too fast.

When astronauts stop being pressed into the floor, they feel like they are floating. They can grow fragile crystals or microbes that would collapse on Earth.

Richard Massey is Royal Society Research Fellow at Durham University



Below: Microgravity makes certain tasks such as eating a meal difficult, as astronaut Leroy Chiao would no doubt attest





STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

What's in the sky?

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You'll find lots of lesser known but fascinating deep-sky objects in and around Orion

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Red light friendly

In order to preserve your night vision, you should read our observing guide under red light

5 DEC



The December Phi-Cassiopeid meteor shower reaches its peak

7 DEC



Asteroid 16 Psyche reaches opposition in Taurus, glowing at magnitude +9.5

8 DEC



The December Monocerotid meteor shower reaches its peak

14 DEC



A total solar eclipse will be visible from Chile and Argentina



14 DEC



The open star cluster NGC 1981 is well placed for observation in Orion at magnitude +4.6

17 DEC



Conjunction between the Moon and Saturn in Capricornus

17 DEC



The Moon, Jupiter and Saturn make a close approach in Capricornus and Sagittarius

19 DEC



December Leonis Minorid meteor shower reaches its peak

22 DEC



The Ursids reach their peak of around ten meteors per hour

23 DEC



Conjunction between the Moon and Mars in Pisces

23 DEC



The Moon and Mars make a close approach in Pisces



EXPLORING OUR NEIGHBOURS THE SUN - OUR LOCAL STAR

SOLAR STORMS AND SPACE WEATHER

Apart from the sunshine that warms us and provides light, the Sun has a greater influence on the Earth and Solar System through the emission of charged particles, or plasma. This was demonstrated in a dramatic way in 1859 when amateur astronomers, including Richard Carrington in the UK, observed a brilliant flare on the Sun through their telescopes. A day later, the aurora hit, what's now known as a geomagnetic storm.



11 DEC
The Sigma Hydrid meteor shower reaches its peak



12 DEC
The Moon will pass in front of Venus, forming a lunar occultation



13 DEC
The Geminids reach their peak of 120 meteors per hour



15 DEC
The Comae Berenid meteor shower reaches its peak



16 DEC
Comet 141P/Machholz makes its closest approach to the Sun at +9.2 in Aquarius



17 DEC
Conjunction between the Moon and Jupiter in Sagittarius



21 DEC
The December solstice



21 DEC
Conjunction between Jupiter and Saturn in Capricornus



21 DEC
The great conjunction of Jupiter and Saturn in Capricornus



28 DEC
Open star cluster NGC 2232 is well placed in Monoceros, glowing at magnitude +3.9



29 DEC
Open star cluster NGC 2244 is well placed in Monoceros, glowing at magnitude +4.8



- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

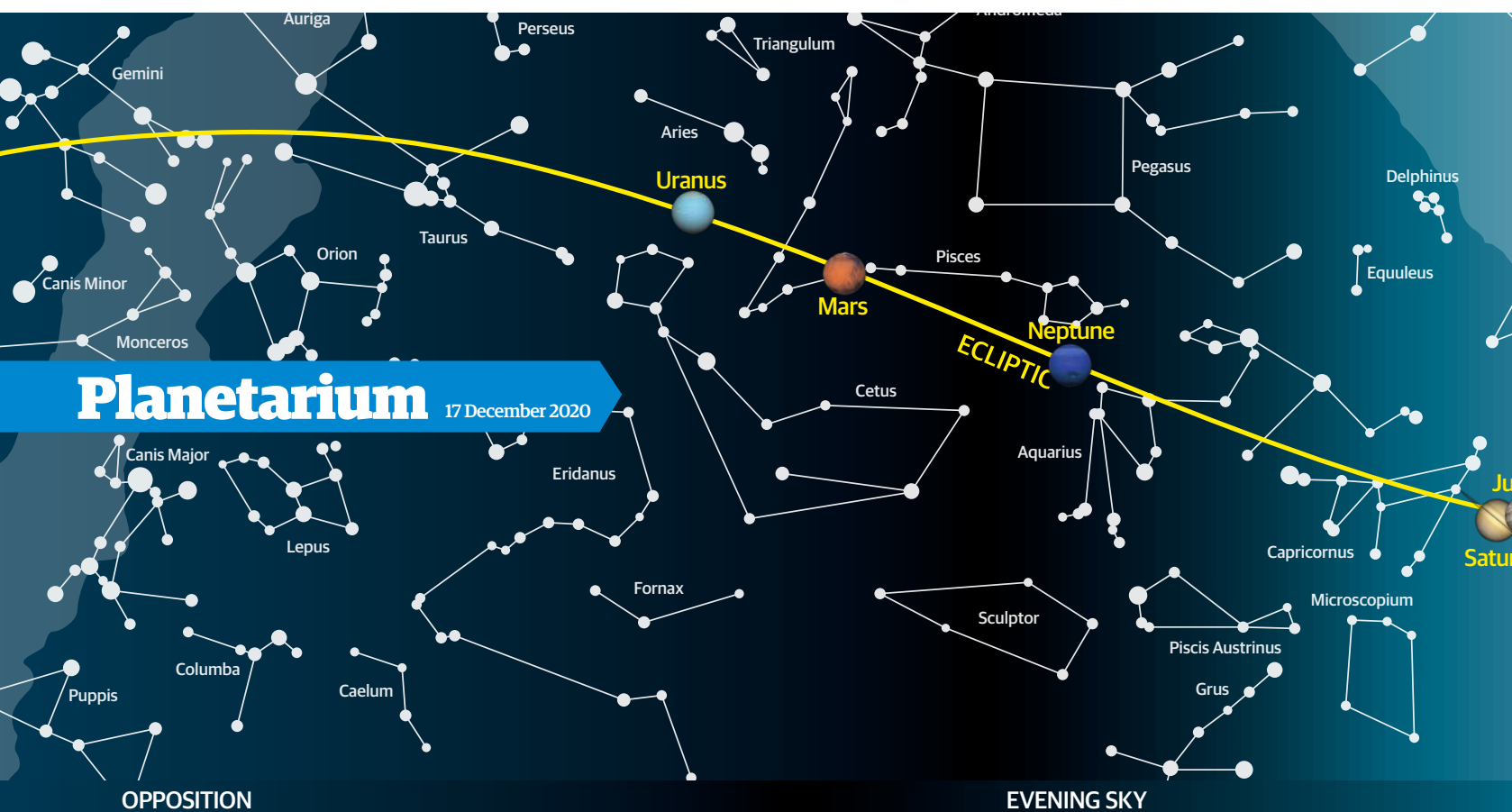
Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.



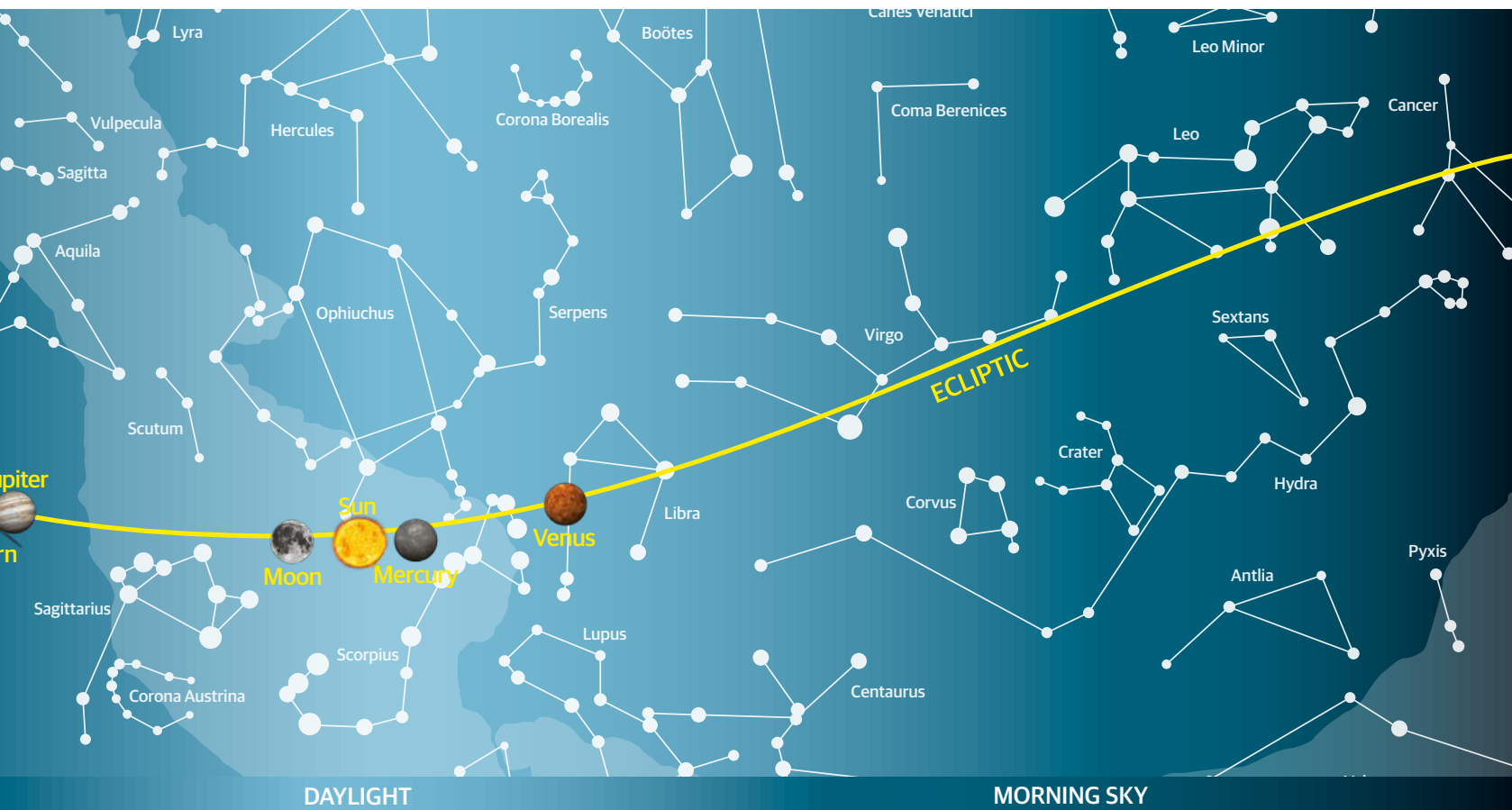


Moon calendar

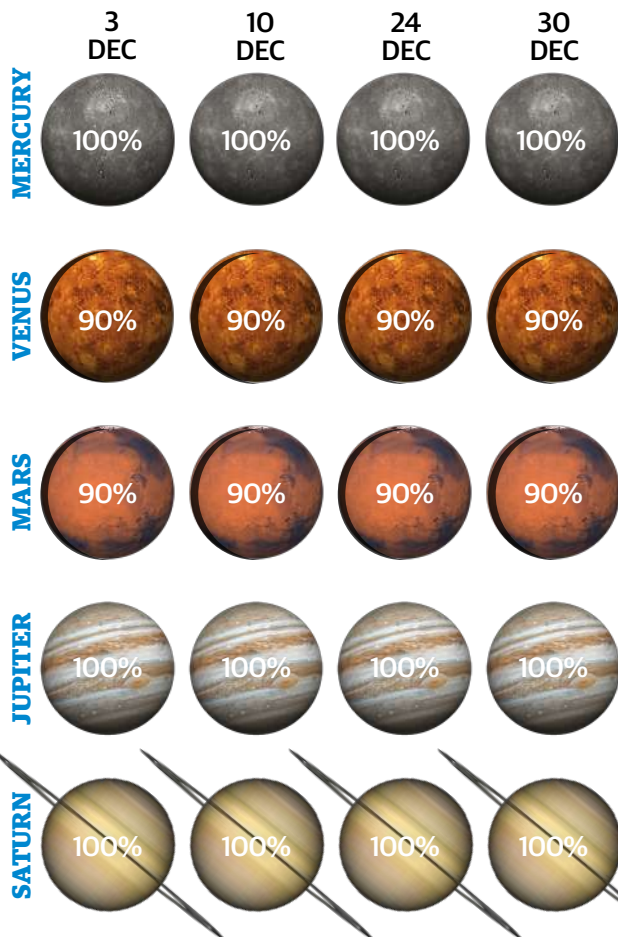
* The Moon does not pass the meridian on 30 December

7 DEC 58.8% 🕒 12:51 🌑 23:13	8 DEC LQ 47.5% 🕒 13:11 🌑 ---	9 DEC 35.9% 🕒 00:34 🕒 13:29	10 DEC 24.9% 🕒 01:57 🌑 13:47	11 DEC 15.1% 🕒 03:21 🌑 14:07	12 DEC 7.3% 🕒 04:48 🌑 14:30	13 DEC 2.2% 🕒 06:16 🌑 15:00	
14 DEC NM 0.1% 🕒 07:42 🌑 15:39	15 DEC 1.0% 🕒 08:59 🌑 16:32	16 DEC 4.9% 🕒 10:01 🌑 17:36	17 DEC 11.1% 🕒 10:47 🌑 18:50	18 DEC 19.0% 🕒 11:21 🌑 20:06	19 DEC 28.1% 🕒 11:47 🌑 21:21	20 DEC 37.9% 🌑 12:06 🕒 22:33	
21 DEC FQ 47.8% 🌑 12:23 🕒 23:43	22 DEC 57.7% 🌑 12:38 🕒 ---	23 DEC 67.1% 🌑 00:51 🕒 12:52	24 DEC 75.8% 🌑 01:58 🕒 13:07	25 DEC 83.6% 🌑 03:06 🕒 13:23	26 DEC 90.2% 🌑 04:14 🕒 13:42	27 DEC 95.3% 🌑 05:24 🕒 14:06	
28 DEC 98.6% 🌑 06:32 🕒 14:37	29 DEC FM 100% 🌑 07:38 🕒 15:18	30 DEC --.%* 🌑 08:36 🕒 16:10	31 DEC 99.1% 🌑 09:24 🕒 17:13	% Illumination 🕒 Moonrise time 🌑 Moonset time			FM Full Moon NM New Moon FQ First quarter TQ Third quarter
All figures are given for 00h at midnight (local times for London, UK)							

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



Planet positions

All rise and set times are given in GMT

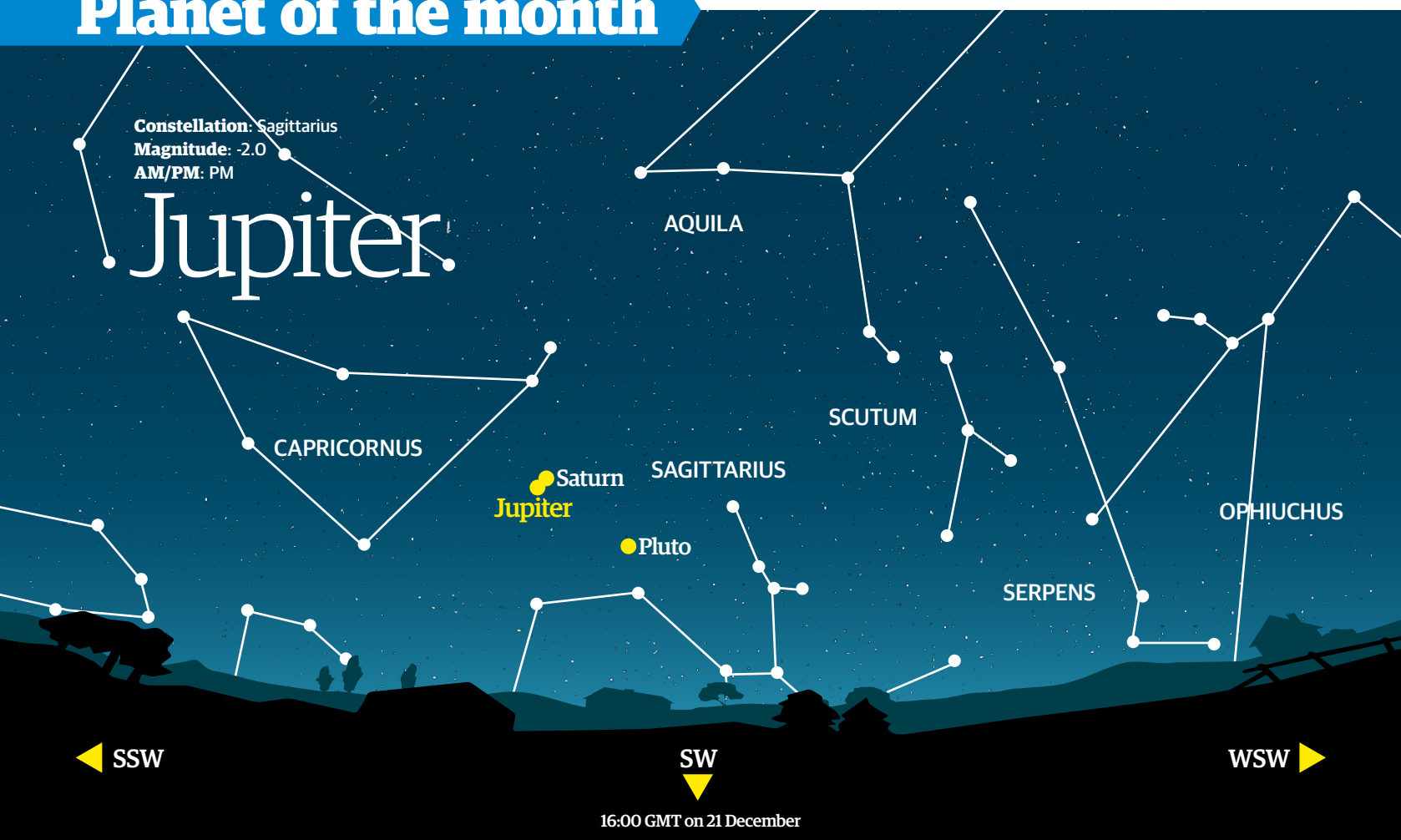
	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	3 DEC	15h 58m 02s	-20° 09' 28"	Libra	-0.8	06:54	15:23
	10 DEC	16h 43m 49s	-22° 45' 53"	Ophiuchus	-1.0	07:29	15:24
	17 DEC	17h 31m 17s	-24° 27' 20"	Ophiuchus	-1.2	08:01	15:32
	24 DEC	18h 20m 05s	-25° 05' 35"	Sagittarius	-1.2	08:43	16:10
	30 DEC	19h 02m 35s	-24° 42' 48"	Sagittarius	-1.0	06:49	15:23
VENUS	3 DEC	14h 47m 48s	-14° 28' 40"	Libra	-4.0	05:10	14:46
	10 DEC	15h 22m 26s	-17° 02' 02"	Libra	-4.0	05:32	14:39
	17 DEC	15h 58m 02s	-19° 13' 53"	Libra	-3.9	05:53	14:33
	24 DEC	16h 34m 34s	-20° 59' 56"	Ophiuchus	-3.9	06:13	14:31
	30 DEC	17h 06m 30s	-22° 07' 27"	Ophiuchus	-3.9	06:29	14:32
MARS	3 DEC	01h 03m 21s	+06° 47' 05"	Pisces	-1.1	13:34	02:54
	10 DEC	01h 09m 40s	+07° 42' 37"	Pisces	-0.9	13:08	02:38
	17 DEC	01h 17m 37s	+08° 44' 55"	Pisces	-0.6	12:43	12:43
	24 DEC	01h 27m 00s	+09° 52' 34"	Pisces	-0.5	12:19	02:11
	30 DEC	01h 36m 01s	+10° 53' 38"	Pisces	-0.3	11:59	02:02
JUPITER	3 DEC	19h 53m 27s	-21° 21' 15"	Sagittarius	-2.0	10:56	19:10
	10 DEC	19h 59m 26s	-21° 05' 01"	Sagittarius	-2.0	10:33	18:50
	17 DEC	20h 05m 40s	-20° 47' 18"	Sagittarius	-2.0	10:10	18:31
	24 DEC	20h 12m 04s	-20° 28' 09"	Sagittarius	-2.0	09:47	18:11
	30 DEC	20h 17m 41s	-20° 10' 38"	Sagittarius	-2.0	09:27	17:55
SATURN	3 DEC	20h 01m 58s	-20° 51' 10"	Sagittarius	+0.6	11:02	19:21
	10 DEC	20h 04m 47s	-20° 43' 16"	Sagittarius	+0.6	10:36	18:58
	17 DEC	20h 07m 47s	-20° 34' 41"	Capricornus	+0.6	10:11	18:34
	24 DEC	20h 10m 56s	-20° 25' 27"	Capricornus	+0.6	09:45	18:11
	30 DEC	20h 13m 43s	-20° 17' 05"	Capricornus	+0.6	09:24	17:51



This month's planets

The great conjunction of Saturn and Jupiter will be a sight to behold in Sagittarius and Capricornus this month

Planet of the month



Our 'Planet of the Month' this issue is mighty Jupiter, not because it is particularly bright but because there will be so much going on around it this month. During December this enormous gas giant planet will have a stunning and exceptionally rare close encounter with its ringed neighbour, Saturn, and will be joined in the twilight by a beautiful crescent Moon, too.

Jupiter will be easily visible to the naked eye this month, looking like a bright blue-white star low in the southwest after sunset. Shining at magnitude -2.0, Jupiter would be strikingly bright in a darker sky, but it will be fighting the twilight and will set only a couple of hours after the Sun, so you won't have long to see it. Through a pair of

binoculars Jupiter will appear much brighter, and you'll see some of its extended family of more than 80 moons. A telescope with higher magnification will show you the planet's cloud bands and the Great Red Spot, a storm the size of Earth that has been raging in Jupiter's atmosphere for centuries.

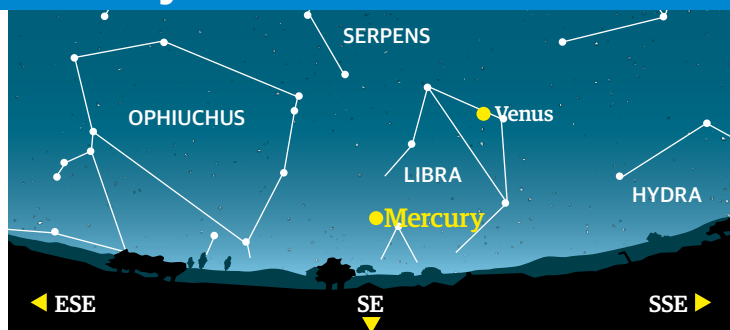
When you look at Jupiter, you'll see another bright 'star' close by, shining to its upper left. This is Saturn, and as December passes the two planets will appear to move closer and closer together until they almost merge into one on the evening of 21 December. On that night they will be just six arc minutes apart, or less than half the width of the full Moon. The view through binoculars will be amazing, and sky-watchers looking at the pair

through telescopes will see them both in the same field of view - a very rare sight indeed. After the 21st the two planets will swap places and move apart again, and by month's end you'll see Jupiter shining to the upper left of Saturn.

A week earlier, as a warm-up act for that cosmic spectacular, Jupiter will be joined in the twilight sky by a very young Moon. After sunset on 16 December a fingernail clipping of a crescent Moon will just be visible to the lower right of Jupiter. On the following evening, 17 December, have your cameras ready to photograph a beautiful slim crescent Moon, with the rest of its face softly illuminated by lavender-hued Earthshine, glowing to the upper left of Jupiter.



Mercury 08:00 GMT on 4 December



Constellation: Scorpius

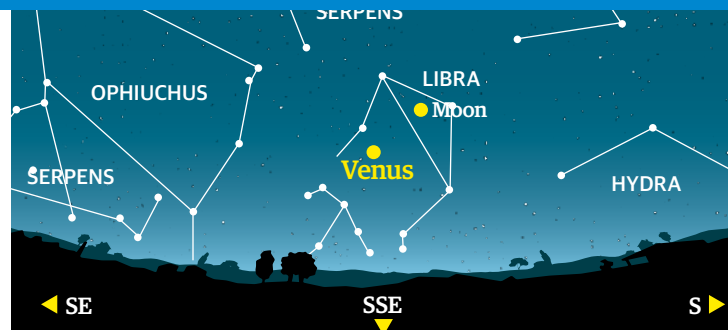
Magnitude: -0.8

AM/PM: AM

This will not be a good month for observing the closest planet to the Sun. Although it shines at a

respectable magnitude of -0.8 at the start of the month, Mercury will be so low in the predawn sky and so close to the Sun that it will be hard to see, and after mid-month it will be lost in the Sun's glare.

Venus 08:00 GMT on 12 December



Constellation: Libra

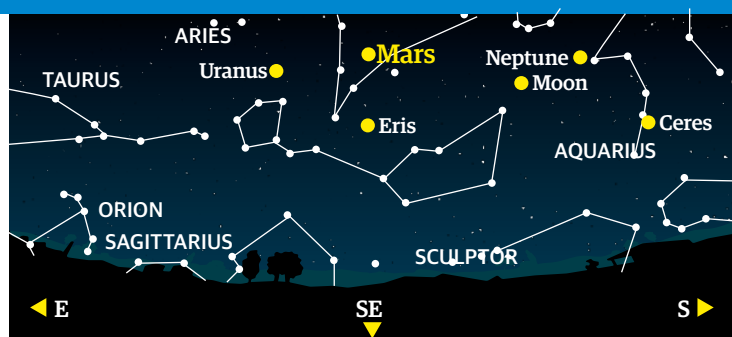
Magnitude: -4.0

AM/PM: AM

Venus is a bright 'morning star' during December, easy to see with the naked eye as a very bright blue-

white star in the east, embedded in the constellation of Libra. However, as December progresses Venus will slowly draw closer to the Sun and will be visible for a slightly shorter time each morning.

Mars 17:00 GMT on 21 December



Constellation: Pisces

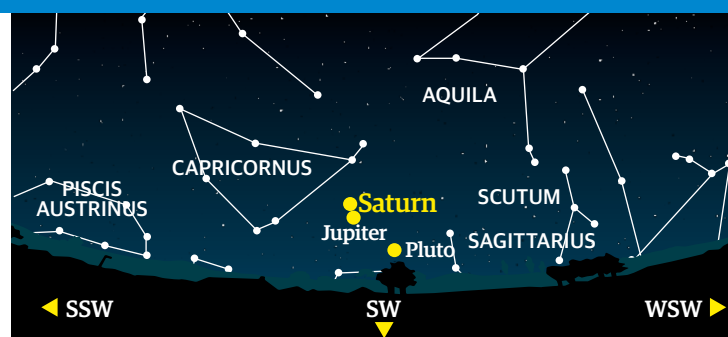
Magnitude: -1.1

AM/PM: PM

Just a couple of months ago Mars dominated the sky. This month the Red Planet - which is actually more

of an orange colour to the naked eye - is visible from sunset to sunrise. You'll first spot it shining low in the east as twilight deepens, and will be able to follow it across the sky until it sets around sunrise.

Saturn 17:00 GMT on 21 December



Constellation: Capricornus

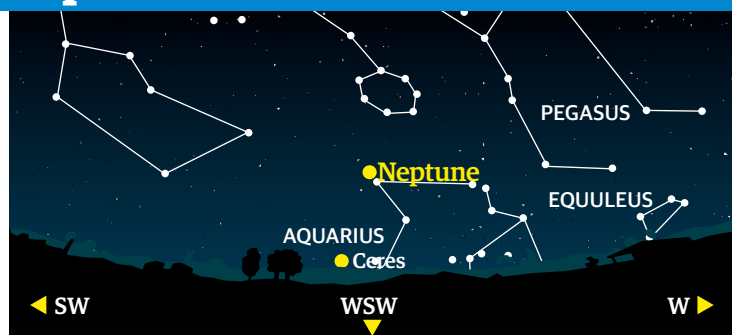
Magnitude: +0.6

AM/PM: PM

Saturn will be a naked-eye star visible in the evening sky this month, forming a very close pair

with much brighter Jupiter. During December the two will appear to pass each other in the sky. During their closest encounter on the evening of the 21st they will be separated by only six arc minutes.

Neptune 21:00 GMT on 30 December



Constellation: Aquarius

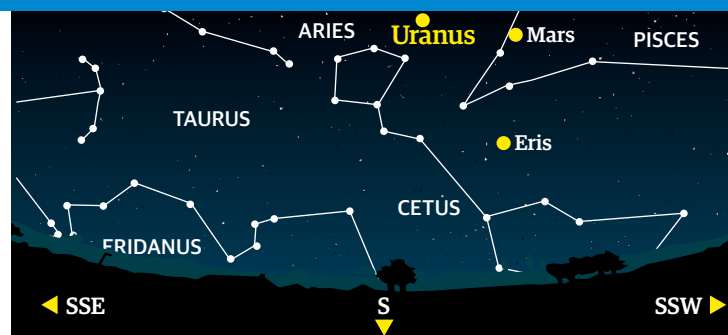
Magnitude: +7.9

AM/PM: PM

This faraway ice giant can be found in the evening sky this month, over to the right of Mars. It will be visible

as soon as the sky starts to darken, but will set at around 23:00. A pair of binoculars or a small telescope will help you pick it out from the background stars because of its turquoise colour.

Uranus 20:00 GMT on 30 December



Constellation: Pisces

Magnitude: +5.7

AM/PM: AM/PM

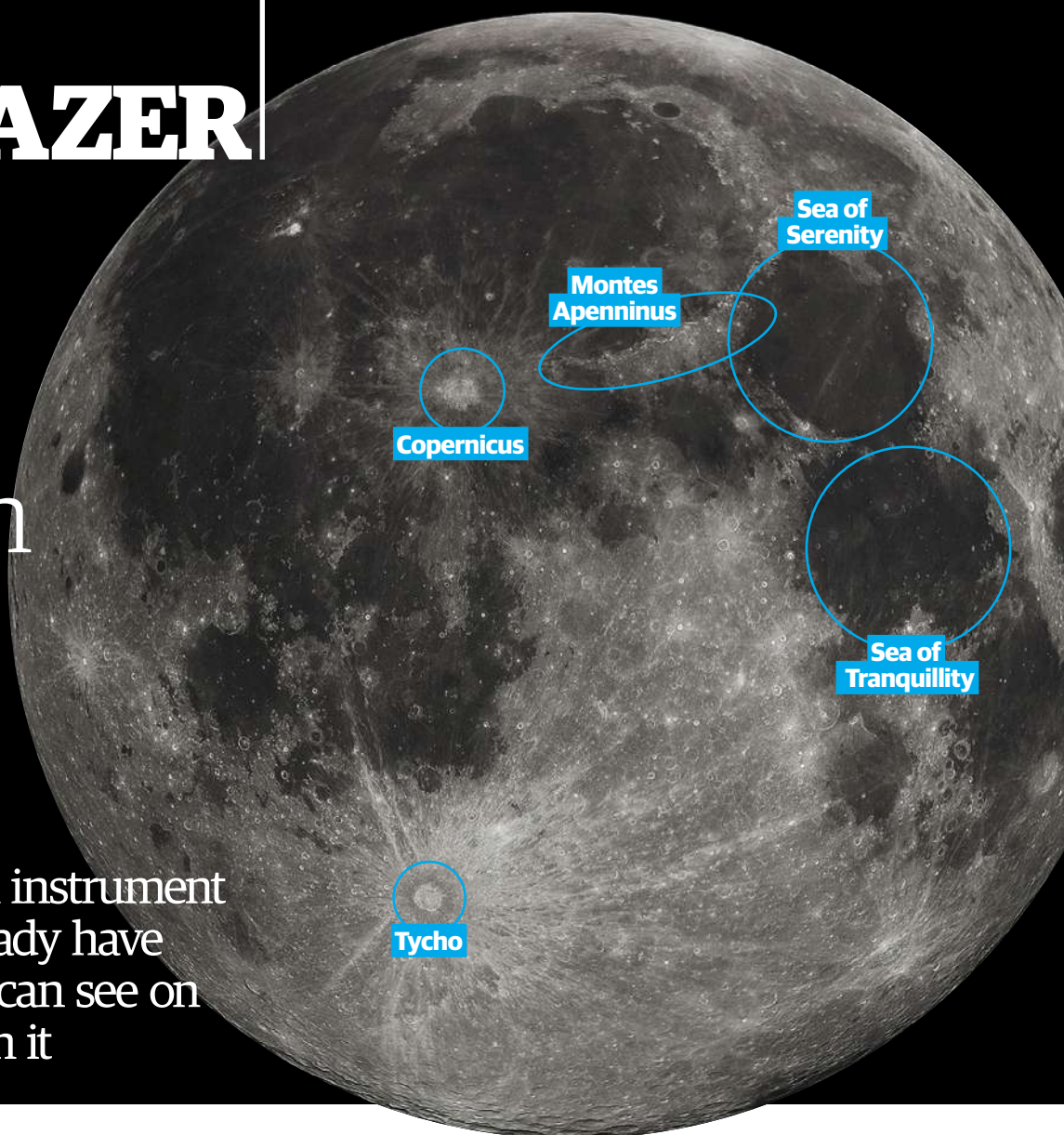
Uranus will be visible in the evening sky. Shining at magnitude +5.7, Uranus is technically a naked-

eye object, but unless you know exactly which tiny point of light it is among thousands of stars of the same brightness you'll need a pair of binoculars to pick it out, using its pale-green colour as a guide.

Moon tour

The Moon through your telescope

If you've asked for an instrument for Christmas, or already have one, here's what you can see on the lunar surface with it



It's true to say that during the lockdown earlier in the year many people discovered the natural beauty of the night sky for the first time; they had no idea that just by looking up from their gardens on a clear night they could see constellations, planets and much more. Many decided they wanted to see even more of the wonders of the universe, and will have received a telescope for Christmas. If you're one of them you'll be eager to turn it on the sky - and your obvious first target is the Moon, which will be high in the sky on Christmas night. But what will you see?

To the naked eye our planet's natural satellite is a small bone-white disc with some dark markings and a couple of bright dots on it. However, seen through even a small telescope the Moon is a stunning sight, covered with fascinating details and features the eye alone can never see.

The first thing you'll notice is that the Moon's face is split into very different light and dark areas. The light areas, which astronomers call the 'lunar highlands', are very rough and made out of countless thousands of holes, or craters, in places packed so close together they seem to overlap. Some of the craters are hundreds of kilometres across, with strikingly sharp raised rims and tall mountain peaks in their centres, while others are much smaller pits only a few kilometres wide. All the large craters and many of the

smaller ones have names honouring astronomers and other famous scientists and explorers.

The dark areas appear much flatter than the highlands, and are spattered with fewer craters too. These are the famous lunar seas, or maria, but they are not seas of water; the maria are areas covered over by molten lava which flowed across the Moon many billions of years ago after huge meteorite impacts. The seas have names too, and you'll already know one of them even if you've never looked at the Moon before - Mare Tranquillitatis, the Sea of Tranquility, where Neil Armstrong took his famous one small step for man in 1969 when Apollo 11 landed on the Moon. You can use our chart above to find it through your telescope. The other seas have romantic and evocative names such as the Sea of Serenity, the Sea of Nectar and even the Sea of Clouds.

Your telescope will show you systems of bright lines radiating away from some craters, like the cracks in a broken shop window. These are called rays, and they are made of rock and dust that sprayed across the Moon after the crater was formed, just as you would get if you threw a stone onto a frozen lake. Craters surrounded by rays are young - in astronomical terms at least. They were formed after the huge lava floods that created the seas. On Christmas night you'll see a crater on the left side of the Moon that

is surrounded by a beautiful system of bright rays. This is Copernicus, the 'Monarch of the Moon', and it is almost 100 kilometres (62 miles) across. Down near the bottom of the Moon you'll see another rayed crater - 85-kilometre (53-mile) wide Tycho. Just like Copernicus, you can tell Tycho was formed relatively recently because its rays are sprayed over older features beneath them.

The Moon has towering mountain ranges too, as dramatic as any on Earth. Through your telescope you'll see a very striking curved feature towards the top centre of the Moon. These are Montes Apenninus, which separate Mare Imbrium from Mare Serenitatis, and they stretch for more than 600 kilometres (373 miles) across the lunar surface. Montes Apenninus comprise over 3,000 peaks, including the highest mountain on the Moon, Mons Huygens, which is 5.5 kilometres (3.4 miles) high.

Those are just some of the features you will see on the Moon the first time you look at it through your telescope. Don't worry about finding out the names of all the craters, seas and mountains straight away - you'll have plenty of time to do that. Instead just enjoy looking at the Moon as you've never seen it before, and as it moves across your eyepiece imagine you're flying over its battered surface in a spaceship, just as the Apollo crews did all those years ago.

Naked eye & binocular targets

Orion dominates the winter sky after sunset. Here are some of its fascinating features and neighbours

1 Betelgeuse (Alpha Orionis)

Shining at magnitude +0.6, this red supergiant, marking Orion's shoulder, is the ninth-brightest star in the sky. 530 light years from Earth, it is 600 times the width of our Sun and would extend halfway to Jupiter if put in our Sun's place. It will explode in a supernova in the future - but when?

2 Alnitak, Alnilam and Mintaka (Orion's Belt)

This striking line of three equally spaced blue-white stars is one of the most famous asterisms in the sky. Although its stars Alnitak, Alnilam and Mintaka all look the same distance from us, they are all spread far apart in space, and the 'belt' they create is just a line-of-sight effect.

3 Orion Nebula (Messier 42)

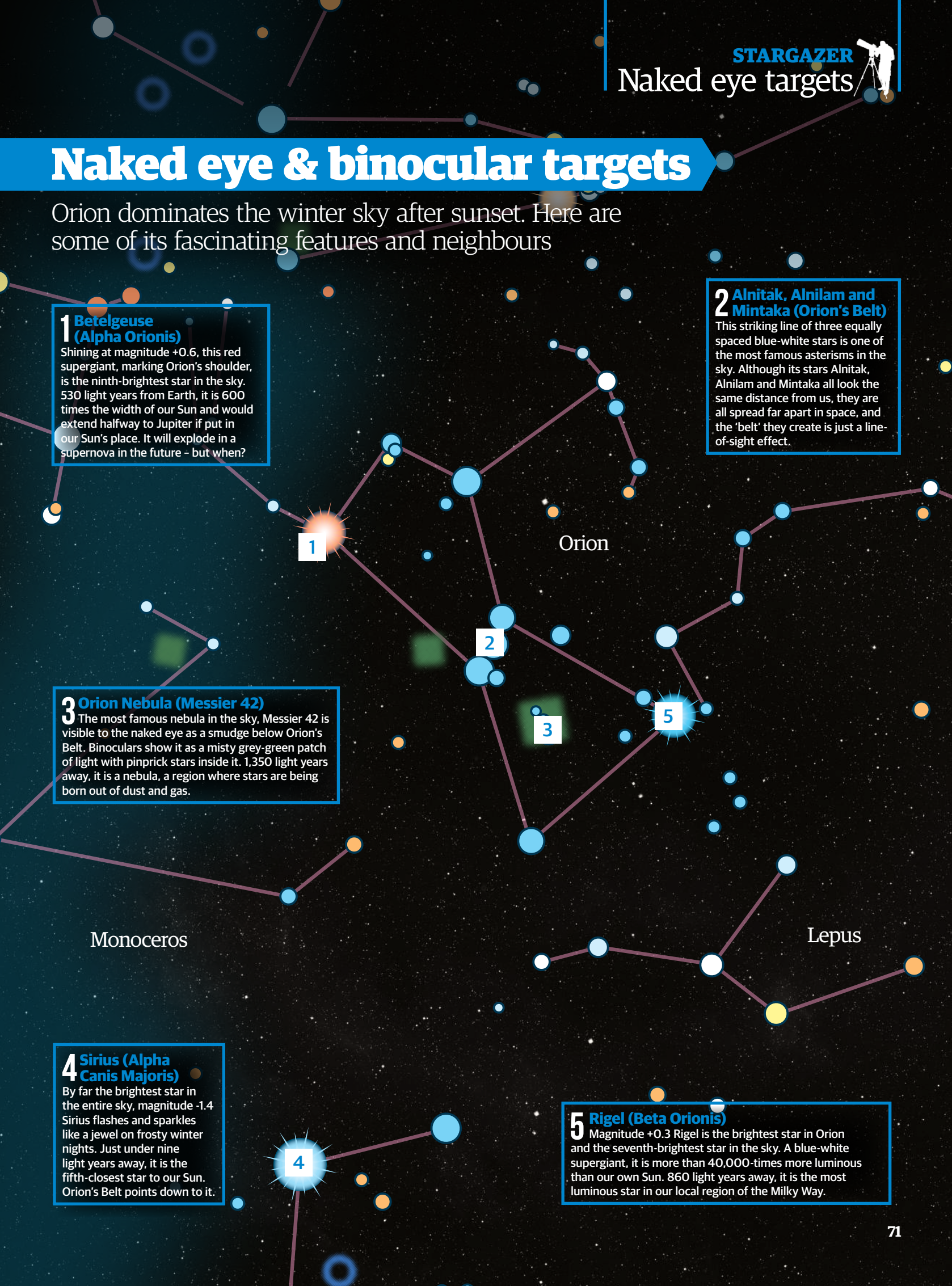
The most famous nebula in the sky, Messier 42 is visible to the naked eye as a smudge below Orion's Belt. Binoculars show it as a misty grey-green patch of light with pinprick stars inside it. 1,350 light years away, it is a nebula, a region where stars are being born out of dust and gas.

4 Sirius (Alpha Canis Majoris)

By far the brightest star in the entire sky, magnitude -1.4 Sirius flashes and sparkles like a jewel on frosty winter nights. Just under nine light years away, it is the fifth-closest star to our Sun. Orion's Belt points down to it.

5 Rigel (Beta Orionis)

Magnitude +0.3 Rigel is the brightest star in Orion and the seventh-brightest star in the sky. A blue-white supergiant, it is more than 40,000-times more luminous than our own Sun. 860 light years away, it is the most luminous star in our local region of the Milky Way.



Deep sky challenge

The Hunter's hidden treasures

If you can drag your eyes away from its most famous nebula, you'll find lots of lesser known but fascinating deep-sky objects

2020 is almost over - good riddance, many will say - but hopefully December will bring with it some sparkling clear and frosty nights for us to sweep with our telescopes. Obviously we will all swing our reflectors and refractors towards the Orion Nebula (Messier 42) and lose ourselves in its clouds of green and grey, but the constellation of Orion has much more to offer than just that faraway stellar nursery. Scattered around ruddy Betelgeuse, searing Rigel and the Belt are a wealth of other fascinating objects definitely worth aiming your telescope at.

But a word of warning before you start your hunt: if a night is clear it will be very cold too, so make sure you dress very warmly and take regular comfort breaks inside to warm up with a hot chocolate. Also bear in mind that the beautiful fresh snow you crump across to get to your observing site will reflect any lights around you, making it seem brighter and much more light-polluted than usual.

Most astronomers, beginner or experienced, have heard of the Horsehead Nebula. It's one of the most famous in the sky, but due to its faintness very few have actually seen it - we'll show you exactly where to look. We'll also point you towards a very puzzling nebula and a double star that is a beautiful sight in any eyepiece on a frosty December night.



Horsehead Nebula
(Barnard 33)



1 The Horsehead Nebula (Barnard 33)

The Horsehead Nebula is one of the most famous in the whole sky, but is essentially just a small, dark notch silhouetted against a brighter background haze. You'll need a large-aperture telescope, averted vision and a perfect sky to see it. A nebula filter will make it stand out more clearly.

2 The Flame Nebula (NGC 2024)

With the much bigger and brighter Orion Nebula so near, the Flame Nebula is often overlooked. Best seen with medium- or large-aperture instruments, it resembles a roughly cone-shaped patch of brightness cut through with darker bands. Using averted vision will help make it pop out of the background.

3 HD 38858

This +6.0 star is worth finding not because of how it looks itself but because it has two fascinating companions: it is orbited by an exoplanet twice the mass of Uranus and is also surrounded by a huge disc of comets. You won't be able to see these, but it's fascinating to know they're there.

4 Hubble's Variable Nebula (NGC 2261)

This small, faint reflection nebula, roughly triangular in the eyepiece of a large telescope, changes in brightness over the course of a few weeks, hence its name. It shines at ninth magnitude but has a low surface brightness, making it a challenging target.

5 Meissa

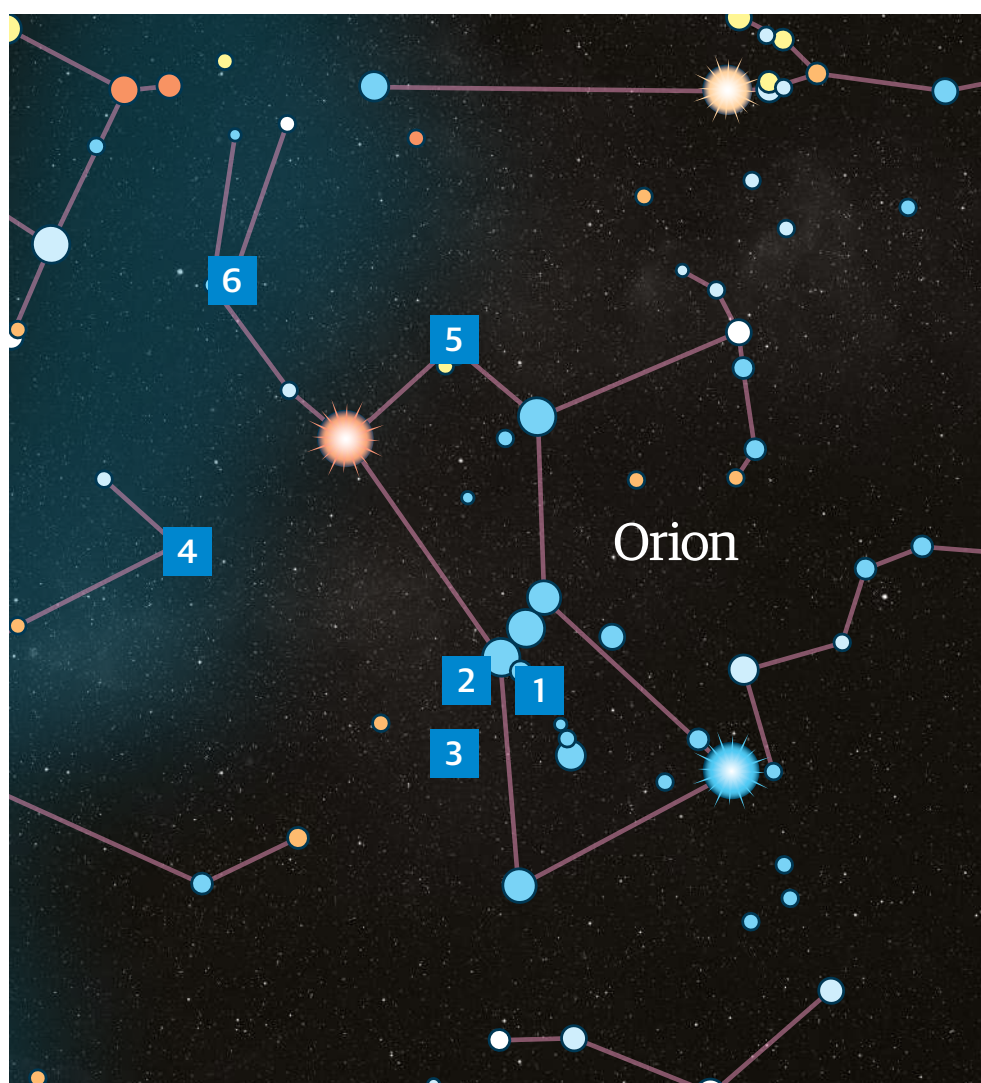
Lost among the brighter, more famous stars of Orion, Meissa is a third-magnitude star with a much fainter fifth-magnitude companion. It's included in our list this month because the contrast between the brighter star's blue colour and fainter star's white colour is striking.

6 Lower's Nebula (SH 2-261)

Unless you're using a large telescope, any moonlight, haze or light pollution will wash away all traces of this wispy, oval-shaped nebula. It is so faint and has such a low surface brightness that finding it is usually a challenge on even perfectly still nights. But if you don't try, you'll never know.



Source: Wikipedia Commons © Judy Schmidt





The Northern Hemisphere

The constellations of December swing into view, offering a plethora of targets

If you're a fan of splitting double stars with your telescope then head over to the constellation of Aries (the Ram), which makes its appearance this month, bounded by the star patterns of Taurus (the Bull), Pisces (the Fishes) and Cetus (the Whale). In particular, binary star systems Lambda Arietis, Epsilon Arietis and Mesarthim are splendid targets to resolve for astronomers with medium- to large-sized telescopes.

Meanwhile orange giants Hamal (the Head of the Ram) and Botein (Little Belly) can be picked out using nothing more than the naked eye. Orion (the Hunter) is also prominent, featuring red supergiant Betelgeuse, De Mairan's Nebula (M43) and the Orion Nebula (M42).

Using the sky chart

This chart is for use at 22:00 (GMT) mid-month and is set for 52° latitude.

- 01 Hold the chart above your head with the bottom of the page in front of you.
- 02 Face south and notice that north on the chart is behind you.
- 03 The constellations on the chart should now match what you see in the sky.



Magnitudes

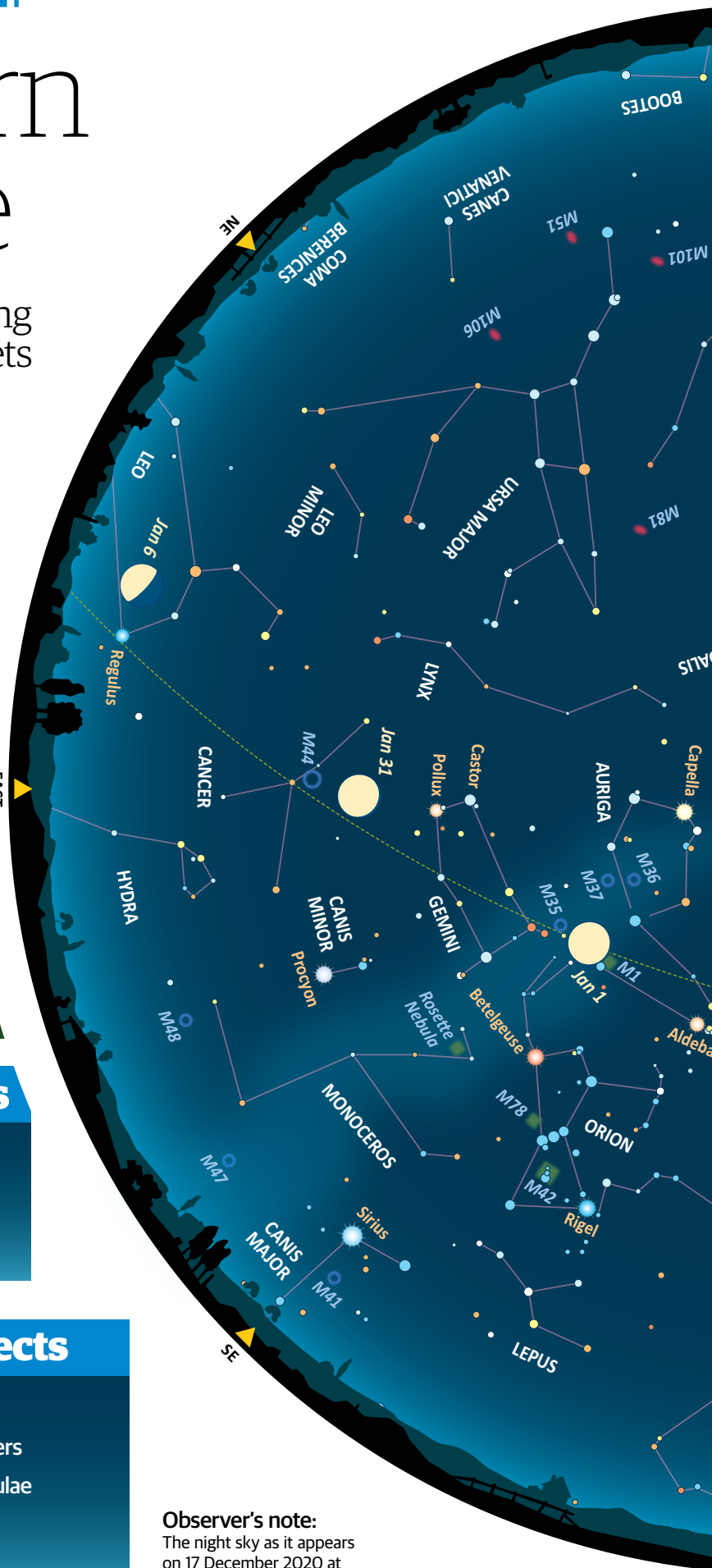
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

- | | |
|-------|-----|
| • O-B | • G |
| • A | • K |
| • F | • M |

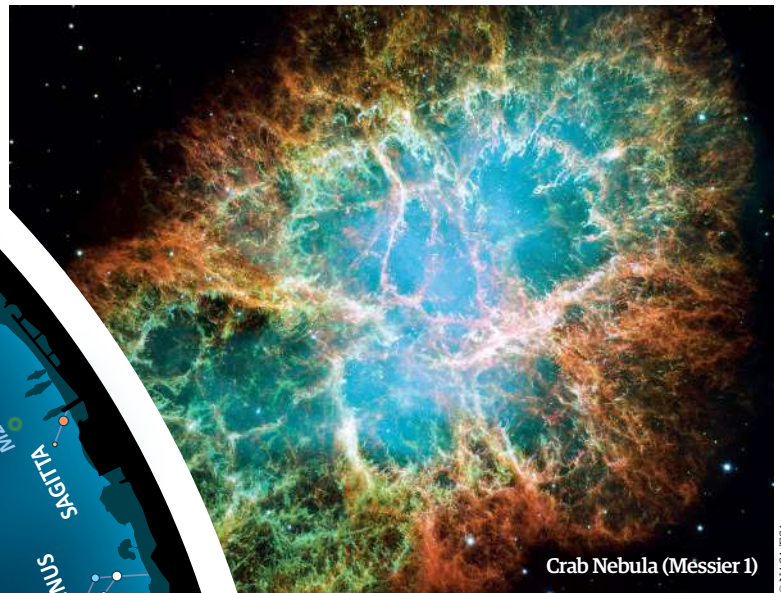
Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



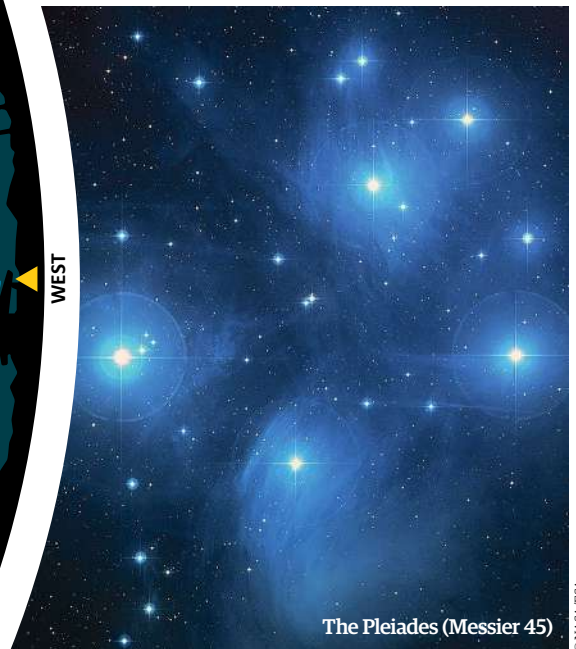
Observer's note:

The night sky as it appears on 17 December 2020 at approximately 22:00 (GMT)



Crab Nebula (Messier 1)

© NASA/ESA



The Pleiades (Messier 45)

© NASA/ESA



Bode's Galaxy (Messier 81)

© NASA, ESA & Hubble Space Telescope



Meade ETX90 Observer

If you're looking for a beginner's telescope that shows you the night sky at the press of a button, this motorised instrument is ideal for you

Telescope advice

Cost: £489 / \$499

From: Amazon

Type: Maksutov-Cassegrain

Aperture: 3.54"

Focal length: 49.21"

Best for...



Beginners



Medium budgets



Planetary viewing



Lunar viewing



Bright deep-sky objects



Basic astrophotography

It's the time of year where some may be considering breaking into the hobby of astronomy and are looking to purchase their first telescope. If you're someone who likes to get observing a specific object as quickly as possible, instead of taking your time in finding your chosen target, then we can strongly recommend a GoTo telescope, which are notorious for taking the fuss out of night-sky navigation. The Meade ETX90 Observer is one such telescope, and features everything the beginner needs, including accessories such as a red dot finder and two 1.25" super Plössl eyepieces of 26mm and 9.7mm, which provide magnifications of 48x and 129x respectively. The packaging provided by Meade Instruments is superb, and for a low cost in comparison to similar telescopes on the market you get a hard carry case for the telescope tube and a 'messenger' bag for the stainless-steel tripod. The ETX90 Observer can be taken to an observing site with minimum fuss, and if you're looking to travel light - and have a tabletop at your destination - you can leave the tripod at home.

To the beginner, the setting up of the ETX90 Observer can look daunting. However - and as always with Meade's products - a comprehensive manual is supplied with the telescope. If you're unfamiliar with how motorised telescopes work, though, we'd recommend that you have a play around with the set-up before you embark on a night of observing. A no-tool set-up boasts convenience, meaning that you don't need to find any tools to put the ETX90 together.

It took us less than half an hour to fully build the telescope. We were pleased to find that the

overall build of the ETX90 is excellent, promising to last for years of astronomy, even with heavy use. With the nights drawing in early, a clear November evening provided the ideal opportunity to test the telescope's mettle on a selection of night-sky targets, particularly the motorised technology. The ETX90 has a small aperture but a decent focal length, which combined with its Ultra-High Transmission Coatings (UHTC) makes it suitable for providing good views of the planets of the Solar System, the surface of the Moon and bright naked-eye objects such as the Orion Nebula (M42), as well as close-up views of star clusters, including the Pleiades (M45) glowing at magnitude +1.6 in the constellation of Taurus, and the Beehive Cluster (M44) in the constellation of Cancer at magnitude +3.7. The ETX90 comes with a built-in library of 30,000 night-sky objects, but it is worth mentioning that you'll be unable to see some of these targets due to the telescope's small aperture. Nevertheless, the ETX90 will slew to the target, allowing you to follow up with a larger aperture at a later date.

Aligning the GoTo is a simple process, especially if you have done it a few times. However, on your first go the system will ask for your location, time and date. Meade has ensured that the ETX series retains memory, and as such you only need to enter these essentials on your first evening. When aligning, we used the compass that slots into the eyepiece hole to ensure that the telescope was sturdy for our observations, and then pointed the set-up north. Turning on the telescope's computer and selecting the 'easy alignment' option, the ETX90 responded rapidly and selected a bright star for alignment without intervention from us. Using the 26mm eyepiece, we centred the telescope's chosen object in our field of view using the arrows on the control, approving it by hitting enter before the motors turned the tube to a second star to ensure that the set-up was fully aligned. We were impressed with the ease of use and are certain that any beginner to astronomy will be able to use the ETX90's system with no problems at all. If you prefer, you can also use the telescope manually.

Before we began instructing the ETX90 to slew to a chosen target, we decided to try out its 'tour feature', which chooses the best targets for you to observe on that particular evening. As the motors slew the tube for you, this also gives you

Left: The objective lens is covered in Ultra-High Transmission Coatings (UHTC) to provide crisp and clear views of night sky objects





Left: The overall set-up of the ETX90 is sturdy and surprisingly light for good portability

Below: The ETX90 is supplied with a fork mount and is packed with the electronics needed for a fuss-free tour of the sky

the opportunity to learn the names of some of the brightest stars in the sky - invaluable information that allows you to navigate the constellations and the night sky as a whole. The motors use an internal battery, and on cold evenings we did discover that the ETX90 seems to 'eat' through batteries - we managed less than seven hours of use before the batteries wore out. At such times we got drive failure issues, forcing us to use a mains supply. If you are someone who likes to travel to remote locations, we recommend a car adapter cable that will allow you to plug it into a power port in your vehicle, or spare rechargeable batteries.

Views of Mars, the Moon and the Orion Nebula were extremely pleasing for a beginner's telescope and are sure to delight the entire family. The telescope's optics also split double stars very well, as we found when we turned the ETX90 to Alcor and Mizar in the constellation of Ursa Major. While we had to turn the focuser a lot to get suitable views between targets, it allows you to fine-tune your field of view, ensuring that the very best sights of the night sky are achieved with the set-up.

For the price, the ETX90 Observer is good value for money, especially when the overall build, accessories and the views are considered. A great starter telescope which doesn't require a great deal of knowledge of astronomy to use, this excellent instrument is also ideal for entry-level astrophotography and trying out some webcam video astrophotography.

"THE OVERALL BUILD OF THE ETX90 IS EXCELLENT, PROMISING TO LAST FOR YEARS OF ASTRONOMY"





STARGAZER

Christmas gift guide

With the holiday season just around the corner, **All About Space** selects the presents that are sure to delight any space fan

Best for all astronomers

Celestron NexStar 4SE

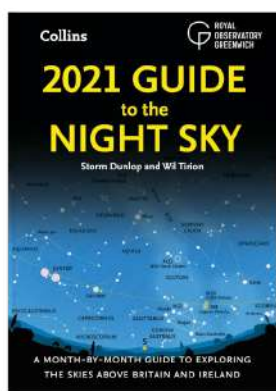
Cost: £479.99 (approx. \$631.80) – price may vary

From: wexphotovideo.com/celestron and other UK retailers

The Celestron NexStar 4SE is a fully computerised and motorised telescope. After a brief set-up procedure, visible objects from your location can be selected on the hand controller and the telescope will move to them automatically. The 4SE will also continue to track the selected object as it appears to move across the sky, keeping it within the view of the eyepiece. The telescope tube is a powerful Maksutov-Cassegrain design, which allows for an extremely long focal length of 1,325mm in a compact body. The four-inch aperture lets in plenty of light for viewing many celestial objects, such as the Moon, planets, star clusters, galaxies, and nebulae such as the Orion Nebula. Power comes from eight AA batteries (not included). Celestron also offers a range of PowerTanks that can be purchased separately for a rechargeable option. In the box is everything needed to get started, including a premium eyepiece with 53x magnification, a sturdy steel tripod with accessory tray and a red dot StarPointer. Additional Celestron eyepieces can be purchased separately to give a wider range of magnifications.



"THE NEXSTAR 4SE WILL ALSO CONTINUE TO TRACK THE SELECTED OBJECT AS IT APPEARS TO MOVE ACROSS THE SKY"



Best for planning your observations

2021 Guide to the Night Sky

Cost: £6.99 / \$14.95 for North American version – price may vary

From: collins.co.uk

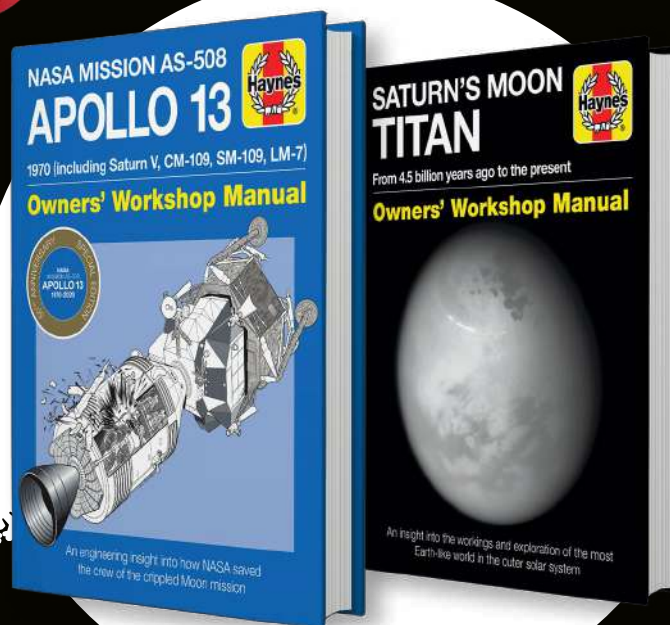
Look to the stars in 2021 with this month-by-month guide to the night sky visible from Britain and Ireland. Approved by the Royal Observatory Greenwich and written by astronomy experts, the handbook is full of easy-to-use star maps and information on what to look out for in 2021. A comprehensive guide for all astronomy enthusiasts, from beginner to seasoned stargazer. A North American version is also available in the US.

Best for the technically minded

Haynes Apollo 13 50th Anniversary Edition and Saturn's Moon Titan

Cost: £25 (approx. \$33) each **From:** haynes.com/space

Haynes has something for everyone this Christmas, with these two fascinating new titles topping the bill. First is an expanded special new edition of the best-selling Haynes Apollo 13 Manual, published to coincide with the 50th anniversary of the mission launched in April 1970, which nearly turned into a catastrophe. This manual chronicles the complex technical challenges involved in returning the crippled spacecraft safely to Earth, the worldwide reaction and the lessons learned. Meanwhile, the Saturn's Moon Titan Manual gives a fascinating insight into a place within our own Solar System where there are very similar conditions to those on ancient Earth, and where scientists are planning to send new and innovative exploratory probes, as they believe there is a possibility of discovering primitive forms of life and of learning more about the development of early Earth.



Best for night sky tours

Night Sky Almanac 2021

Cost: £9.99 / \$16.95 **From:** collins.co.uk

Follow the progress of constellations throughout the seasons with this beautiful companion to the night sky. Written by astronomical experts and approved by the Royal Observatory Greenwich, the *Night Sky Almanac 2021* is the perfect gift for amateur and seasoned astronomers.

Best for beginners to astrophotography

Meade Infinity 76

Cost: £109.99 (approx. \$149.99) **From:** currys.co.uk

Introduce your loved ones to the wonders of the night sky this Christmas with the Meade Infinity 76 - the straight-from-the-box, no-nonsense telescope designed to get astronomers of every age and ability stargazing in minutes. Even the youngest family member can join in and begin a lifetime of learning about space. Aspiring astrophotographer? Perfect! Exclusively included with the Infinity 76 is Meade's universal smartphone mount, so snap it on and share all those stunning celestial views. Smooth tracking controls and a detachable red dot finderscope help provide a limitless supply of stars, planets and other space objects to locate and discover, conveniently packing away within the signature Meade blue travel bag for astronomy on the go.





STARGAZER



Best for young scientific minds STEM-X Launch Prize

Cost: \$105 (approx. £78) – get 10% off with discount code ALLSPACE20, for a limited time only

From: launchprize.com

Ever dreamt of being part of the space program? Now's your chance... This virtual challenge takes you one giant leap closer, as you design your very own space experiment. It's a challenge for 12 to 19 year olds that is out of this world – literally!

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- Build your experiment with NASA astronauts and space scientists
- Watch your space mission launch on a SpaceX rocket
- Get exclusive access to the SpaceX VIP launch party
- \$2,000 (approx. £1,500) spending money
- Visit two of Orlando's world-famous theme parks

Are you ready for liftoff?



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FOR YOUR
EXPERIMENT

"WITH HELP FROM ASTRONAUTS AND SPACE SCIENTISTS, YOU'LL DESIGN AN EXPERIMENT THAT COULD LAUNCH ON A SPACEX ROCKET"

Best for beginners to astronomy

Celestron 114AZ-SR

Cost: £149.99 / \$179.99 – price may vary

From: currys.co.uk / kohls.com

The Celestron 114AZ-SR is a perfect telescope for beginners to astronomy. Expect dazzling views of the Moon, planets, stars and brighter deep-sky objects, such as the Orion Nebula. The 114mm-aperture reflector-design optical tube is large enough to gather 265-times more light compared to the naked eye and is wrapped in a unique carbon-fibre effect finish. Perfectly suited for beginners, the alt-azimuth mount allows point-and-shoot style movement in all directions and is easy to set up. Quickly getting subjects into view of the eyepiece is easy using the included StarPointer, which projects a red dot for object targeting. Capture images or video with your smartphone by attaching it to the eyepiece with the included smartphone adapter. In the box is everything needed to get started, including two eyepieces with 23x and 62x magnification, a tripod with accessory tray, a red dot StarPointer and smartphone adapter. Additional Celestron eyepieces can be purchased separately to give a wider range of magnifications.



12

FREE DIGITAL SPACE GIFTS

FOR EVERY READER!

TEACH YOURSELF ASTROPHOTOGRAPHY

Night-sky photography can seem very daunting at first, but it's one of the most rewarding genres to embark on, and is actually far easier than it looks. The photographic possibilities that the night sky offers are incredibly vast, from landscape shots with the Milky Way behind them and capturing stunning star trails to photographing far-away planets and galaxies. Unearth the difference between galaxies and nebulae, find out when to shoot the Moon and learn how to capture an aurora. Whether you are a novice or seasoned space expert, **Teach Yourself Astrophotography** has something for you. Inside we've included jam-packed features, in-depth tutorials, interviews with pros and creative projects. Discover professional tips and tricks that will enable you to shoot the stars with absolute ease. We've even covered all of the essential kit that will aid you in taking breathtaking images that are truly out of this world.

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You don't need an encyclopaedic knowledge of the skies or even a telescope to get into stargazing. That's the beauty of astronomy: armed with nothing more than your eyes and a basic grasp of where to look, you can embark on one of the most rewarding hobbies. Planets, stars, constellations, nebulae, meteor showers and many other celestial objects can be spotted using only the naked eye. And for those with telescopes, the universe – a myriad of colours and awe-inspiring sights – is your personal gallery of a trillion cosmic wonders. Our easy-to-follow guides will furnish you with all the essentials, taking you on a journey from stargazing hobbyist to becoming a fully equipped astronomy enthusiast. With practical guidance, seasonal sky charts and pointers on how to spot some of the sky's most accessible sights, this new edition of **Astronomy for Beginners** will be your companion as you unravel the beauty of the night sky.



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Guion Bluford

He was the first African American astronaut to fly into space

Guion Bluford applied to become a NASA astronaut in 1977, but he didn't hold out much hope. After all, it was the first time in ten years that applications had been sought, and he was acutely aware that 8,079 people had applied - with just 35 places on offer.

Yet Bluford was always in with a very good chance. As an officer and fighter pilot in the US Air Force, he'd received his pilot wings in January 1965. He'd gone on to fly 144 combat missions with an F-4 squadron in Vietnam before teaching cross-country and acrobatic flying and gaining a master's degree in aerospace engineering in 1974.

He also graduated four years later with a PhD in aerospace engineering and a minor in laser physics, so there was no doubt that Bluford - who was born on 22 November 1942 in Philadelphia, Pennsylvania - had enjoyed a distinguished career. Indeed, he was living his dream given that he'd built model aeroplanes as a child and decided to become an aerospace engineer from the moment he attended junior high school.

As an African American, Bluford's opportunities were greatly boosted when NASA announced its new class of recruits was going to include female and non-white astronauts for the first time. The space agency also said it wanted a mix of pilots and mission specialists for what was to become Astronaut Group 8 - with Bluford fitting both of these requirements.

When the call finally came, Bluford was out on government travel. A note was placed on the door of his hotel room in Washington, DC, and when he called back that evening he received the news he had longed for: confirmation that he was going to be interviewed and put through his paces.

Having successfully completed this gruelling process, he was selected to become a NASA astronaut in January 1978. He became mission-ready in August the following year, and although he worked on the development of flight software for STS-1 and other important supporting tasks, his big chance came in 1983 when STS-8 was launched from the Kennedy Space Center in Florida, with Bluford assigned as one of the three mission specialists.

Upon takeoff aboard Challenger on 30 August, Bluford became the first African American person to go into space. He was also only the second person of African descent to embark on a space



Guion Bluford remained in the US Air Force while he was assigned to NASA

mission, and his work was of great importance. Aside from assisting with the launch of the INSAT-1B communications and weather satellite for India, he was to perform experiments with electrophoresis using live cell samples to better understand the biophysical effects of spaceflight.

Following a successful mission, he was next assigned to STS-61A in 1985 - the last successful flight of Challenger. This was a scientific Spacelab mission directed and funded by West Germany, taking a crew of eight to the orbital laboratory module to conduct experiments related to functions in microgravity. The following year, after Bluford heard about the Challenger disaster, which killed all seven crew members after breaking apart 73 seconds into its flight, his work became focused on payload safety.

Bluford flew again in 1991 as a crew member of STS-39 to conduct payload experiments for the Department of Defense. His final mission was STS-53 a year later, again in support of the Department of Defense, and in total he logged more than 688 hours in space across four flights. He left NASA and retired from the US Air Force the following year, and was inducted into the International Space Hall of Fame in 1997. He also spent a lot of time sharing his passion for aerospace engineering with black students, helping to inspire whole generations.

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